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Volume Six *Number One*

SCHOOL OF MINES AND METALLURGY

UNIVERSITY *of* MISSOURI

BULLETIN

AUGUST, 1921
Technical Series

THE PROBLEM OF THE ST. PETER SANDSTONE

ROLLA, MISSOURI

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SCHOOL *of* MINES *and* METALLURGY

UNIVERSITY *of* MISSOURI

THE PROBLEM OF THE ST. PETER SANDSTONE

By

CHARLES LAURENCE DAKE

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University.

ROLLA, MISSOURI
1921

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THE PROBLEM OF THE ST. PETER SANDSTONE

INTRODUCTION.

INCEPTION OF THE INVESTIGATON.

The following study of the St. Peter sandstone was first undertaken as an economic problem, when the writer was preparing a report on the glass sands of Missouri. The work, however, offered a notable opportunity for a study of the character and origin of a formation that has for many years been a puzzle to students of sedimentation.

GRADUAL CHANGE OF VIEWS.

The writer had for some time been impressed with the importance of continental deposits, and with our lack of appreciation of their abundance. Following certain ideas which had been growing in strength about that time, he was biased in favor of the desert origin of the sandstone and went to work with the idea of collecting data to prove that premise. During the course of his studies, however, the impression was gradually forced upon the writer that the eolian theory of origin was untenable, and this impression finally strengthened to the firm conviction that the formation is in fact of marine origin.

The writer feels that some significance attaches to the fact that the conclusions finally adopted were entirely contrary to the preconceived ideas held when the study was begun. There was no prejudice whatever in favor of the interpretation presented in the present paper.

STATEMENT OF THE PROBLEM.

The problem has been to establish, so far as possible, the general conditions of derivation and deposition of the St. Peter and associated formations, with an attempt at the same time to evaluate the criteria usually employed in the solution of problems of this character. The paper has been divided into three parts, or chapters, as follows:

Chapter I is devoted to a detailed study of the stratigraphy of the St. Peter and associated beds, throughout the area in which the St. Peter is known to occur. This phase of the problem is presented geographically, by states. The discussion of Missouri stratigraphy is based very largely on the writer's own field observations conducted through five field seasons devoted chiefly to studies of Missouri Ordovician formations. The information from other states has been, necessarily, almost wholly a matter of compilation, but is presented here for the convenience of the reader, and to place in proper perspective all the elements of the problem. This first chapter presents little in the way of interpretation, being largely a citation of the facts on which the conclusions of the final chapter are based. While a general knowledge of these facts is essential to a proper understanding of the problems discussed later, and while it is hoped that this information will be of special value to stratigraphers as a rather complete summary of the available information, yet a distinct effort has been made to present the discussion of Chapters II and III in such a way as to make them entirely understandable for those who wish the general conclusions of the paper, without taking the time to read the mass of detail presented in Chapter I. The major features of this chapter are graphically presented in Plates I-IV.

Chapter II deals with those more intimate characteristics of the St. Peter sandstone itself which are believed, or have been believed by others, to throw light on the conditions of its derivation, transportation, and deposition. Among the characteristics considered are composition, including iron content, clay content, and the like; textural features, such as size, uniformity, rounding, and frosting of grains; and structural phenomena, such as bedding, cross-bedding, ripple-marks, and sun-cracks.

In this chapter, an attempt has been made to evaluate the criteria in general and to determine their specific application to the

St. Peter. The conclusion is reached that several of the criteria usually held to indicate eolian origin are: first, of less positive significance than is generally believed; second, significant only of conditions of transportation, and not of deposition; third, sometimes inherited from an older formation; and fourth, not present in the St. Peter in any appreciably greater perfection than in other sandstones of the same region known to be marine. On the other hand, it is pointed out that structural features are imposed on a formation at the time it is laid down and cannot be inherited; and are, therefore, the only positive criteria as to conditions of deposition. These criteria point rather definitely to the marine origin of the formation.

In Chapter III is presented a summary of the geographical conditions under which the formations of the early and middle Ordovician of the Mississippi Valley region were derived and deposited. The conclusion is reached that the clastics were yielded by a rather low land mass to the north, the climate of which was humid, allowing of deep and complete weathering which kept well in advance of erosion. The region, because of a lack of vegetation common to all early Paleozoic time, was particularly favorable to active wind-work, and lying, as it is believed to have lain, in the belt of prevailing westerlies, gave a good opportunity for the removal of finer clay by wind drift to the east, while the rivers delivered the sand to the south into the sea. This process, going on from Potsdam time to St. Peter, may very logically account for the small amount of clay in sands derived from crystalline sources, an amount much less than should normally develop from average igneous rocks. It is further pointed out that the erosion of the Beekmantown limestones in the pre-St. Peter interval would normally uncover a large bordering belt of already assorted and rounded Potsdam sandstone, which, under similar conditions of wind-drift and sorting would also contribute largely to the St. Peter seas, thus insuring the high degree of purity and rounding of that formation. Attention is also called to the fact that if prevailing westerly winds existed then, as now, conditions would not be particularly favorable for wind-drift of the St. Peter from the northern source into the area now occupied by it, as has been supposed by some.

CHAPTER I

STRATIGRAPHY OF THE ST. PETER AREA.

No one can gain an adequate conception of the history through which the typical St. Peter region went, in early Ordovician time, without making a careful study of the stratigraphy of the various formational units both above and below the St. Peter, as well as of that formation itself. Since the larger part of the field work done by the writer on this problem has been limited to Missouri, and since it is believed that certain conditions there discovered are of critical value, the details of the stratigraphy for that state will first be presented. Following this will be given a summary of the known facts in each state in which the St. Peter occurs. And finally, from this information, the broad important features of the stratigraphy of the entire area will be brought together. These data are graphically summed up in plates I-IV.

MISSOURI

Roubidoux

In Missouri, the rocks of definite Beekmantown age have been divided into four formations. Of these, the lowest is called the Roubidoux, and was known in older reports as the Second Sandstone, and as the St. Elizabeth formation. Ulrich,[1] in his earlier work, included this and the succeeding Jefferson City in his Ozarkian, but later work has shown the undoubted Beekmantown age of these beds, and the Ozarkian is now restricted by Ulrich to include no beds higher than the Gasconade, next beneath the Roubidoux.

The detailed tracing of these beds was carried on during the summers of 1919 and 1920 by the writer, and the results will be published in the forthcoming new edition of the Missouri state geological map.

---

[1] Ulrich, E. O., Revision of the Paleozoic systems, Bull. Geol. Soc. America, vol. 22, 1911.

Locally, there is evidence of slight erosion below the Roubidoux, the base of the formation enclosing chert pebbles derived from the underlying cherty limestone. The formation, which varies between 75 and 200 feet in thickness, consists of a complex of chert, limestone, and sandstone. Lateral gradations from sandstone into chert or limestone are frequent and the changes rather abrupt, so that no two sections of the formation are entirely comparable, even though in closely adjacent localities. In Dent, Shannon, Crawford, and bordering counties, sandstones make up much of the formation, with chert and limestone less common. To the east, to the west, and to the south, however, limestone becomes much more abundant, locally making up more than three-fourths of the total thickness. The sandstones are moderately fine grained, closely resembling the St. Peter in that respect (see pp. 153-165). The grains vary from well-rounded to angular, and while picked samples can be compared from the two formations, which are practically indistinguishable, the average of the Roubidoux, owing to its greater quartz enlargement, appears distinctly more angular than the St. Peter (plates XIII-XX). The sandstone members of the Roubidoux are notably cross-bedded, and abundantly ripple-marked. The ripples vary from extremely regular oscillation types, to the most irregular and unsymmetrical current varieties.

Sun cracks are abundant. They are of a somewhat unusual type, and have already been described by the writer[2]. As commonly seen, they appear as ridges on the upper surface of ledges, in place, and resulted from the cracking through of thin mud layers, which because of their lesser resistance, are usually worn away, as soon as the cracks are exposed, and are therefore rarely seen. This explanation was advanced, in the above-quoted paper, though no examples had been seen to verify the conclusions reached. Since then, however, the writer has collected thin slabs of sandstone, with interbedded shaly layers between, the shaly layers being cracked through and filled with sand, which upon solidification shows as columns passing through the shale bed and apparently continuous with the sandstone layers above and below.

---

[2] Cox, G. H., and Dake, C. L., Geological criteria for determining the structural position of sedimentary beds; Missouri Univ., School of Mines, Bull., vol. 2, No. 4, 1916.

The sun cracks suggest shallow waters and indicate occasional actual emergences. Nevertheless the formation is clearly marine throughout, as indicated by marine fossils in the interbedded cherty limestone members, at all horizons; and by the lateral gradation of the marine cherty limestone into the sandstones. It should be noted that no fossils have been found in the sandstone members of the formation, though the general conditions of deposition were moderately favorable to marine life, as shown by the fossils in the cherty limestones at numerous horizons, in some of which fossils are locally very abundant. It is important to bear this in mind when considering the scarcity of fossils in the St. Peter.

While chemical analyses of the Roubidoux sandstone members have not been made, careful comparison of samples of this sandstone with others which have been analyzed indicates that it would probably average 97 or 98 per cent silica, being in this respect rather comparable with the St. Peter, though slightly less pure. A notable feature is the absence of shales, the sandstone itself being very free from clay particles, and no shale beds in excess of an inch or so thick being noted. Interbedded limestones are slightly argillaceous, and in places very thin bedded. But true shales of any considerable thickness are practically unknown, the sandstones in all cases grading laterally into cherts or limestones.

Evidence as to the age of the formation has been collected by Ulrich at numerous localities, though he has published few faunal lists. Fossils collected by the writer from beds in place, at DeSoto, in the topmost two or three feet of the formation, were identified by Ulrich as follows:

Lecanospira—two species.
Euconia or Roubidouxia n. gen.
Eccyliomphalus aff. multiseptarius Cleland.

Of these, Ulrich says "All are typical Roubidoux fossils, and the last occurs in the basal Canadian (Tribes Hill limestone) in New York." Another small lot collected by the writer from chert float, believed to occur lower in the Roubidoux, in Bollinger County, are listed as follows by Ulrich:

Lecanospira sp.
Hormotoma aff. H. artemesia (Billings).
Lophospira, a small undetermined species.
A small round-whorled gastropod suggesting the genus Holopea.

Ulrich reports that, "these fossils indicate post-Gasconade and probably are of Roubidoux age."

Some interest attaches, also, to the probable source of the sand in the Roubidoux. As has already been pointed out, the rapid increase in marine limestone in the formation, both to the east and west is characteristic. This surely precludes derivation of the sands from those directions. To the south, information, while less abundant, shows at least one or more important limestone wedges, which seem to thicken to the south, and play out northward. Unfortunately, in this direction the Roubidoux passes beneath younger beds, and is not open to study. The same geological horizon does not reappear until the Ouachita uplift is reached. There, as will be seen in the descriptions of the Arkansas stratigraphy, the beds presumed to be of the same age consist of much more shaly sandstones and shales, somewhat calcareous[3], which presumably were deposited in the Ouachita geosyncline, and derived from a land mass to the south. It is quite improbable that the very pure sands of the Roubidoux were derived from this direction. Additional information will will be given, relative to this point, in the further consideration of the Arkansas sections (pp. 48-52).

It has been suggested by several that the St. Francois Mountains, with their pre-Cambrian crystalline core, themselves furnished much of the sand for the production of these beds. Considerable study by the writer has led to the conclusion, however, that contrary to the prevailing opinion at the present, little, if any, of this basement was exposed as late as Roubidoux time. At many places where the Gasconade or older Eminence laps against the old crystallines, the contact seems to be the result of faulting. Formations higher than the Gasconade, so far as could be detected, contain absolutely no fragments of granite or porphyry, or no crystals of feldapar. Neither do shales occur more abundantly near the old basement, in the limestone series. A careful study of the Roubidoux does not show any increase in feldspathic material as the complex is approached. If any of the basement at all remained emerged as late as Roubidoux time, which seems quite doubtful, the area must have been small, and no important amount of sediment could possibly have been contributed by it to the Roubidoux seas. It seems almost certain, then, that the Roubidoux sand was derived from the north. This conclusion is of interest with respect to later discussions as to the source, also, of the St. Peter sands.

---

[3] Miser, H. D., Manganese deposits of the Caddo Gap and DeQueen quadrangles, Arkansas; U. S. Geol. Survey, Bull. 660, 1918, pp. 66-68.

Jefferson City.

This formation is a portion of what was known in the older reports as the Second Magnesian Limestone. Locally, there is a very thin chert conglomerate, at the contact of the Jefferson City formation on the Roubidoux, indicating at least local emergence and slight erosion.

In the published reports that deal with this formation in Missouri, it is made to include everything from the Roubidoux below to the St. Peter group above. As a result of recent detailed mapping in Ste. Genevieve County[4], this formation has been split up into Jefferson City (restricted) at the base, followed by Cotter and Powell. Similar divisions had already been recognized in Arkansas. (See pp. 38-41). While it is still impossible, over most of the Ozark region, to draw the boundaries between these units, it is thought best to call attention to the known presence of each, since it allows of a more thorough comparison with adjacent regions. The term "Jefferson City Group" will be used to indicate all three.

The Jefferson City restricted consists dominantly of thin-bedded, slightly argillaceous dolomites, with thin sandstone beds, in the form of more or less discontinuous lenses, from a few inches to ten feet or more in thickness. Shale beds up to four inches in thickness are known, but are uncommon. Ripple marks are common, both in the sandstones and in the limestones, and sun cracks have been noted at a few horizons even in the limestones, though it seems certain that the Jefferson City represents slightly deeper waters, or at least more uniform and stable conditions of sedimentation than obtained in Roubidoux time. Marine fossils are found at several horizons. Over most of the state, the true Jefferson City probably does not greatly exceed 200 feet in thickness. While no exact measurements have been made, it is believed that the thickness increases southward, and may be double that amount, near the Arkansas border, along White River.

---

[4] St. Clair, Stuart, unpublished manuscript of forthcoming report.

Cotter.

Above the Jefferson City rests the Cotter formation. In Missouri, it has been mapped in detail, only in Ste. Genevieve County.[5] It is known, however, to extend from there southwestward continuously to the White River Country in Arkansas. Northward, its distribution is less well known, tho Cotter fossils have been found in chert float in Phelps county.

Like the Jefferson City, the Cotter consists largely of cherty dolomite, slightly argillaceous in places, but without important shale beds. Thin sandstones are present, and one sandstone member probably near the middle of the formation, is wide-spread over southern Missouri, from Perry county southwest to Ozark and Douglas counties, and reaches a thickness of at least 20 feet. It is strongly cross-bedded and ripple-marked. The writer has seen no sun cracks in this bed. The Cotter varies in thickness. There is apparently unconformity between it and the Powell, which accounts in part for this variation. On White River, along the Missouri-Arkansas line, 500 feet have been measured, the base not being exposed.

Fossils collected by the writer in south central Bollinger county were identified by Ulrich, who lists them as follows:

Ceratopea sp.

Hormotoma aff. artemesia.

Two species of involute cephalopods; one small, the other about 4 inches in diameter, and both related to the genus Tarphyceras.

Pygidia of two species of trilobites.

Two species of bivalved crustacea; one an Isochilina, the other an Eopteria.

"All of these fossils," reports Ulrich, "are clearly indicative of the Cotter formation of the Canadian system."

---

[5] St. Clair, Stuart, unpublished manuscript.

Powell.

The Powell rests on the eroded surface of the Cotter formation. This erosion is considerably more notable than that between the Jefferson City and Roubidoux, evidences for which have been secured only locally. In Missouri, the formation has been mapped in detail only in Ste. Genevieve county, where it has an important development.[6] It is, however, known to be present south of Ste. Genevieve county, rather persistently. To the north, the areas have been examined with less care, and it is not possible to say whether or not the Powell extends much beyond Jefferson county.

The formation consists dominantly of slightly magnesian limestone, in which shale beds are very sparingly developed but which carries thin sandstone lenses, never over ten feet thick. In Missouri, the entire formation probably rarely exceeds 200 feet in thickness.

No Powell fossils have been collected by the writer, but abundant faunas are reported from Arkansas, and will be described under that state. (See p. 40).

St. Peter group.

Under this head are described those formations which have usually in Missouri been described and mapped as the St. Peter sandstone, though some of the beds have been mistaken in places for Jefferson City. In older reports the formation is usually referred to as the Saccharoidal or First Sandstone, less commonly as the Pacific sandstone, the Crystal City sandstone, or the Cap au Gres sandstone. Recent work in Missouri, of which the writer has done the larger part, has traced out the boundaries of this group in much detail, and has shown what is already known in Arkansas, that the St. Peter as formerly delimited is clearly divisible, over much of the area, into two formations, the Everton at the base and the St. Peter (restricted) above. In Ste. Genevieve county these beds have been mapped by St. Clair[7] in much detail, while at the same time the writer has traced them across Jefferson county and northward, and across Perry county and south. The results of the writer's

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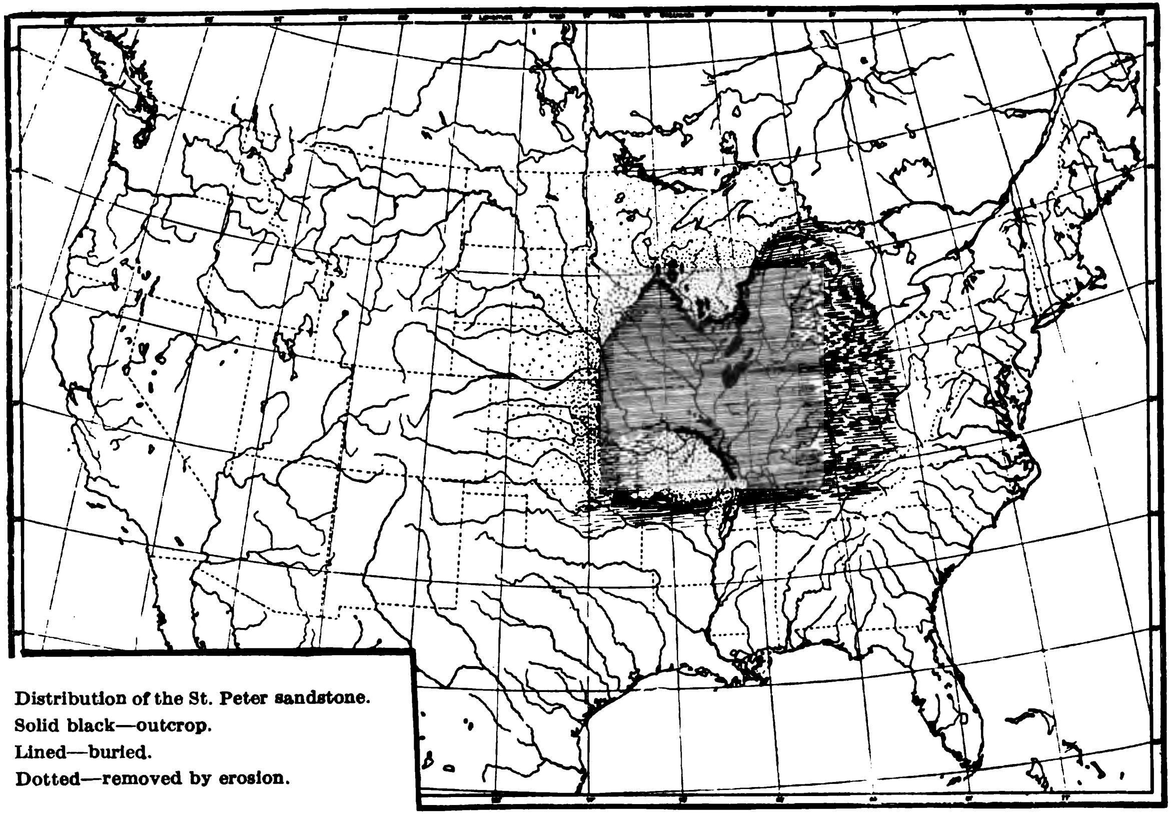
[6] St. Clair, Stuart, unpublished manuscript.

[7] St. Clair, Stuart, unpublished manuscript.

PLATE III.



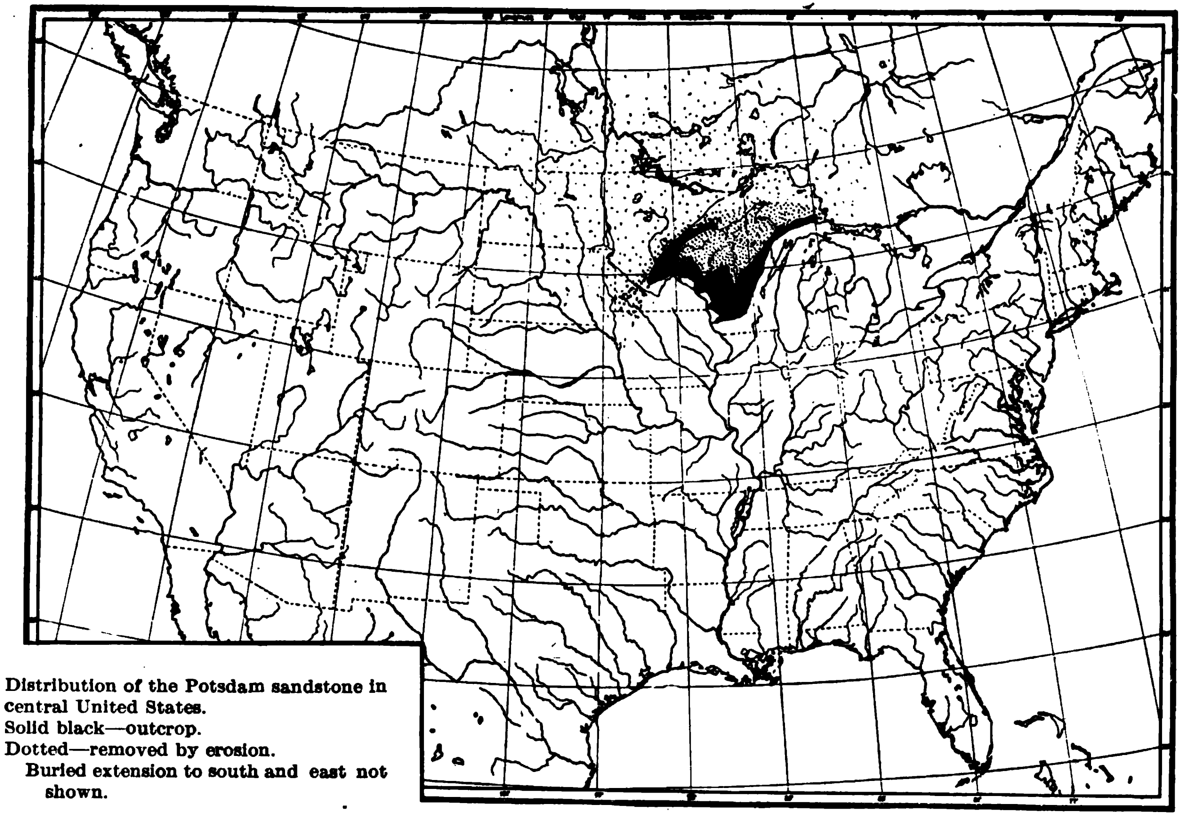
Distribution of the St. Peter sandstone.

Solid black—outcrop.

Lined—buried.

Dotted—removed by erosion.

PLATE IV.



Distribution of the Potsdam sandstone in central United States.
Solid black—outcrop.
Dotted—removed by erosion.
Buried extension to south and east not shown.

mapping of the St. Peter group has already been presented on county maps, in his report on the "Sand and Gravel Resources of Missouri,"[8] and will be summarized on the forthcoming new edition of the Missouri State geological map. Each formation will be described separately.

Everton.—In Missouri, the Everton consists of two members, a basal group of sandy beds, and an upper limestone. Owing to the eroded surface on which they rest, the basal beds vary rapidly in thickness from place to place. In Ste. Genevieve county and south, they rest chiefly on the Powell limestone, though it is possible that erosion has in places removed the Powell, leaving the Cotter exposed in pre-Everton time. This is also probably the case in Jefferson county. Farther north, the Powell, if present, must be very thin, and it is believed that the St. Peter series rests largely on Cotter, and probably in places even on Jefferson City. Local relief must be as great as 40 feet, on the pre-Everton land surface which is marked by basal chert conglomerate and red residual soil.

The lower member of the Everton consists of a dominantly sandy phase, but with some interbedded limestones. The upper member is a sandy limestone. The writer has found no fossils in either member, but beds of similar stratigraphic position in Arkansas, resting on the eroded surface of the Powell, and overlain by typical St. Peter, have yielded small marine faunas both near base and near top. These will be described in the section on the stratigraphy of that state (p. 42).

The general character and thickness of the Everton is shown by the following sections:

NW. ¼ Sec. 30, T. 36N., R. 10E., near Giboney, in Perry County.

St. Peter,	60 ft. massive sandstone.
Everton,	25 ft. sandy dolomite. 20 ft. massive quartzitic sandstone.
Cotter or Powell,	85 ft. cherty dolomite.

Center Sec. 33, T. 40N., R. 6E., Jefferson County.

Joachim,	gray dolomite.
St. Peter,	65 ft. massive gray sandstone.
	15 ft. covered.
Everton,	20 ft. cross-bedded sandy dolomite. 35 ft. thin-bedded sandstone, base not exposed.

---

[8] Dake, C. L., Sand and gravel resources of Missouri; Missouri Bureau Geol. and Mines, 2nd Ser., vol. XV, 1918.

Center Sec. 20, T. 40N., R.6E., Jefferson County.

Joachim,	gray well-bedded dolomite.
St. Peter,	65 ft. massive gray sandstone.
Everton,	40 ft. irregularly cross-bedded sandy dolomite.
	35 ft. massive white sandstone.
Cotter or Powell,	20 ft. cherty dolomite.

SW. ¼ Sec. 36., T.41N., R.5E., Jefferson County.

Joachim,	gray dolomite.
St. Peter,	60 ft. massive white sandstone.
Everton,	55 ft. sandy gray dolomite.
	18 ft. sandstone, chert pebbles at base.
Cotter or Powell,	30ft. gray to buff dolomite.

NE. ¼ Sec. 27, T. 41N., R. 5 E., Jefferson County.

Joachim,	thin-bedded gray dolomite.
St. Peter,	40 ft. massive white sandstone.
	10 ft. covered.
Everton,	15 ft. sandy dolomite and thin sandstone beds.
	15 ft. thin-bedded sandstone.
	10 ft. interbedded sandstone and dolomite.
	10 ft. conglomerate with dolomite and chert pebbles in a sandy matrix.
Cotter or Powell,	20 ft. gray cherty dolomite.

SW. ¼ Sec. 5, T.41N., R.5E., Jefferson County.

Joachim,	well-bedded gray dolomite.
St. Peter,	35 ft. massive white sandstone.
Everton,	20 ft. sandy dolomite.
	50 ft. thin-bedded, cross-bedded, ripple-marked sandstone, with thin dolomite layers.
	5 ft. conglomerate of chert pebbles in a sandy matrix, base not exposed.

Sec. 34, T.42N., R. 4E., Jefferson County.

Joachim.	thin-bedded gray dolomite.
St. Peter,	35 ft. sandstone.
Everton,	5 ft. sandy dolomite.
	15 ft. thin-bedded sandstone.
	5 ft. cherty dolomite.
	5 ft. sandstone, conglomeratic at the base.
Cotter or Powell,	buff dolomite.

The last of the above sections represents the most northern point at which the Everton is recognized in Missouri as a distinct unit. In Section 7 of the same township and range are exposed about 70 feet of sandstone, with no limestone throughout. It is believed that this thickness represents both Everton and St. Peter; but with the thinning out of the limestone, allowing the two sandstones to come together, their proper separation is impossible.

In the S. ½ Sec. 3, T.49N., R.2E., in Lincoln county, a thin layer of limestone was noted, with St. Peter outcropping both above and below it, on the hillside. Contacts were not visible. At the time this outcrop was visited, the presence of the Everton was not suspected in Missouri, and this layer was accounted for on the basis of faulting, since it is in close proximity to the Cap au Gres fault. It is suspected, however, on the basis of later discoveries, that this may represent the Everton horizon.

Mr. Malcom Wilson[9], who has in preparation a new report on the underground water resources of Missouri, reports wells in the northern part of the state, in which the St. Peter occurs in two parts, with a limestone between. This presumably also represents the Everton. Details will be presented in Mr. Wilson's forthcoming report.

Shepard, in a report on the "Underground water resources of Missouri"[10] gives logs of several wells in the western part of the state, in which some limestone occurs within what is referred to as St. Peter sandstone. One record near Carthage, in Jasper county, credits the St. Peter with 85 feet, the upper 60 feet described as white sandstone, with small rounded quartz grains, and the lower 25 feet as sandstone with some chert and siliceous gray limestone.

One well at Springfield is reported to show 16 feet of St. Peter, described as 8 feet of porous sandstone above, and 8 feet of limestone with some sand at the base, the whole overlain by the Joachim limestone. Another Springfield well is described as showing 35 feet of St. Peter (?), the upper 20 feet of which is reported as a sandstone, yellowish gray in color, fine-grained, iron-stained, and with calcareous cement. Below this is 10 feet of light gray siliceous limestone, with 5 feet of light colored, fine-grained sandstone at the base. The record is missing for the 20 feet next above the upper sandstone, but above that is said to be 60 feet of Joachim.

A well near Sheldon, in Vernon county, is reported to contain 30 feet of St. Peter, the upper 10 feet of which is described as white sandstone, the lower 20 feet being flint and limestone, with white rounded pebbles of sandstone. This is said to be below the Devonian.

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[9] Personal communication.

[10] U. S. Geol. Survey, Water Supply Paper, No. 195, 1907.

At Nevada, in Vernon county, a well is reported to show 43 feet (a misprint, and should be 93) of St. Peter, with 10 feet of white sand at the top, underlain by 45 feet of limestone, below which is 23 feet of sand, and 15 feet of flint at the base. These beds are all assigned to the St. Peter, which is said to be overlain by the Joachim. Another well at Nevada is reported to show 100 feet of fine sandstone. This is in remarkable contrast to the well just cited, but attention is called to the extreme imperfection of this log. Dr. Shepard "feels little doubt that some of the material described as sandstone in the log is limestone."

At Clinton, in Henry county, the St. Peter is reported to be 30 feet thick. The upper 10 feet is described as being fine-grained blue chalcedonic flint, siliceous limestone with marcasite crystals, and iron-stained sand (rounded grains of quartz). The next 10 feet is described as the same, with finer rounded grains (probably St. Peter sandstone). The bottom 10 feet is coarser, with more rounded grains of quartz, with siliceous white magnesian limestone. The overlying beds are reported as the Joachim.

Two wells at Malta Bend, in Saline county, report respectively 75 feet and 80 feet of St. Peter, and no reference is made to the presence of limestone. A well at Higginsville, in Lafayette county is said to pierce 150 feet of St. Peter sandstone, in which no limestone is reported. In a diamond drill hole at Raytown, near Kansas City, correlated by E. O. Ulrich, 64 feet of sandstone is reported as St. Peter, no limestone being described. (See folio 206.)

Detailed discussions of the above logs are not given, and it is not possible to say why, in any given case, the limestones were included in the St. Peter. Presumably it was done because of the character of the sand grains in the sandy limestones. The known occurrence of limestones in the St. Peter group in the eastern flank of the Ozark renders such an explanation plausible enough. It would be unsafe, however, to base any very certain conclusion on these logs. In the first place, correlation of formations from churn drill cuttings is more or less difficult. Added to this is the fact that some, at least, of the cuttings were not available to the geologist, who was forced to work out his correlations from drillers' logs, which are notoriously imperfect.

Owing to the overlap of the Mississippian formations across the limestones of Beekmantown age, on the west flank of the Ozark, outcrops of the St. Peter, at best, are very few on this border of the uplift. Moreover the age of much that has been called St. Peter in this region is open to serious dispute. Very similar sandstones, clearly derived from the St. Peter, but quite as clearly of later age, occur at numerous points in and bordering the Ozarks. Such are known of Devonian, Pennsylvanian, and probably of Tertiary age. Some, at least, of these, are so lithologically like the St. Peter, as to defy identification on that basis alone. Some of those of Devonian age, at least in Ste. Genevieve county, carry Devonian fossils. Those of Pennsylvanian age rest above patches of Mississippian, while those of presumably Tertiary age are closely associated with known Tertiary in the Southeast Lowland of the State. In addition, portions of the Roubidoux, the Jefferson City, and the Cotter are also so similar to the St. Peter, as to be very difficult of separation in well logs.

The fact that such similar beds are known, emphasizes the need of caution in correlation. The beds described in these wells rest beneath Mississipian limestones and hence cannot belong to the Pennsylvanian or Tertiary formations to which reference has just been made. They might, however, in some instances, belong to the Devonian, to the Roubidoux, or even to sandstones within the Jefferson City or Cotter.

If these beds represent the St. Peter, the limestones prevailingly described near the center and lower part are quite probably of Everton age. If they are not of St. Peter age, then quite as probably the St. Peter does not exist in these sections, or else is wholly limestone and not recognized.

If the St. Peter is absent, such a condition might be explained by its complete removal in the pre-Devonian erosion, which is known to be important in the Ozark region. Or it might be possible that it was not deposited in this region, the Joachim overlapping onto the Beekmantown beds. In this connection it is interesting to note that in Montgomery and Callaway counties, which mark the westernmost extent of the continous belt of St. Peter outcrop, on the north flank of the Ozarks, the variation in thickness of the St. Peter is extreme, ranging from 10 feet to 100 feet. The former figure is the least known thickness of the St. Peter, where not reduced by later erosion.[11] This might represent merely a higher and more rugged area on the pre-St. Peter erosion surface, or it might indicate the actual fringing out of the St. Peter, on the west.

From the statement of possibilities just given, it is obvious that the information to be secured from these well records must be accepted with reservations. The writer is inclined to the opinion that these limy beds reported as St. Peter may, in a few cases, represent the Everton horizon, recognizable on the west flank of the Ozarks, practically as far north as Kansas City. Northward, no wells are known deep enough to penetrate this horizon. Farther to the northeast, limestones have been reported locally, within the St. Peter (p. 17). Limestones are also reported from several wells in the St. Peter of Iowa (pp. 69-71).

While the Everton consists essentially of two phases, a sandy one below and a limey one above, these are hardly distinct enough, in Missouri, to warrant calling them members, or assigning separate names. The lower sandy phase, in places, is quite as thick as the typical St. Peter, is fully as white and massive, shows essentially the same degree of purity (99.50 and 99.30 per cent silica), and consists of quite as perfectly rounded and frosted grains, seemingly derived from the same source, under very similar conditions. In other places these basal beds, occupying an identical stratigraphic position, are slightly more argillaceous, and carry limestone layers interbedded. The sandstones, where better bedded, are strongly rippled, the ripples being of the oscillation type, and small, averaging not over one-half an inch from crest to crest.

Even this lowest division is clearly marine, though it represents the first deposits on an old erosion surface which here shows a relief known to be at least 40 feet, and probably more. The higher division is everywhere a sandy limestone.

St. Peter.—The St. Peter outcrops in the Ozarks as a narrow border on the north, east and south slopes of the uplift, the southern belt occurring in Arkansas. On the west, outcrops are rare, if present at all, the formation being overlapped by Carboniferous beds. Within the central Ozark area there are many isolated patches of sandstone, which were referred by the older workers to the Saccharoidal or First sandstone (St. Peter). Most, if not all, of those are now known to be of later age, though it is believed that they contain a considerable admixture of reworked St. Peter sand. A few are probably Devonian. More are probably Pennsylvanian as shown by pockets of coal or associated carbonaceous shale; by red and purple fire clays known to be characteristic of the Pennsylvanian elsewhere in the state; and by one case at least where the sandstone incloses a bowlder of fossiliferous Mississippian chert. In a few rare cases these outliers may consist of a core of unworked St. Peter, grading up into the reworked material, but no such case can be pointed to with certainty.

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[11] Dake, C. L., Sand and gravel resources of Missouri; Mo. Bureau Geol. and Mines, Vol. XV, 1918, p. 166.

In southern Missouri and Arkansas, the St. Peter formation rests on the Everton, except locally, where the latter appears to be absent, with the St. Peter overlapping the older beds. Farther north, where the Everton dolomite thins out and disappears, the two sandstones come together, and are wholly indistinguishable. In this area it is not practicable to attempt any separation, and while it is certain that the equivalents of both formations are present, the term St. Peter is still used to refer to both.

On a previous page (p. 16) it has been shown how the Everton dolomite thins out and disappears. Further evidence that the sandstones to the north include both horizons is to be had in a consideration of the average thickness of the formations. In the area where the Everton is recognized, as a separate formation, the St. Peter ranges from 35 to 65 feet in thickness, and 7 measurements show the combined thickness of the two to be 105, 140, 135, 133, 100, 110, and 65 feet. These figures are arranged in order from south to north, and the last of the group shows conditions at the farthest point north to which the Everton could be traced as a distinctive formation. North of this the total thickness as given in a previously published paper[12] is variable but close to the figures given above, for the total thickness of the combined formations. In St. Louis county it is over 80 feet, and at Klondike, in St. Charles county, it is 105 feet. In Warren county the least thickness noted was 50 feet, and the greatest 135, while in Montgomery county the minimum section measured was 10 feet, and the maximum 100 feet. This is total thickness, where no part has been removed by later erosion, and certainly suggests that the beds to the north include both Everton and St. Peter equivalents. This is seemingly contrary to the view of Ulrich, as expressed in a diagramatic section of the Ozark dome, in his paper on the "Revision of the Paleozoic Systems"[13], where he indicates the disappearance of the Everton northward by overlap; especially since he specifically calls attention to the failure of the Everton to reach Missouri.

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[12] Dake, C. L., Sand and gravel, pp. 153-166.

The relations of the St. Peter to the Everton are by no means clear. Ulrich referred[14] to the gradation of the Everton limestone below into the St. Peter above, as the only good case he knew of the rare phenomenon of gradation of sandstone upward into limestone. Such an interpretation would certainly simplify the history of the region being studied. Other work, however, seems to show this to be an erroneous view, inasmuch as Purdue[15] has described in an earlier paper, which Ulrich seems to have overlooked, notably irregular, presumably eroded surfaces at the upper contract of the Everton, beneath the St. Peter. This evidence of an unconformity has been re-emphasized by Purdue and Miser[16] in a more recent paper.

In Perry and Cape Girardeau counties, in southeastern Missouri, there appears also to be evidence of erosion between the deposition of the Everton and the St. Peter, though the information is by no means conclusive. A little farther north, in Ste. Genevieve county, the erosion surface is very obscure, if present at all, and north across Jefferson county no physical evidence of such a break could be detected, either as an uneven surface of the Everton limestone or as conglomerate at the contact. So many well-authenticated cases are now known, however, of marked hiatuses of which there is but little, if any, physical evidence, that the absence of such evidence is admittedly by no means conclusive. Nevertheless, the facts presented below are thought to indicate that the unconformity actually dies out northward.

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[13] Bull. Geol. Soc. America, vol. 22, 1911, pp. 450 and 479.

[14] Ulrich, Revision, p. 529.

[15] Purdue, A. M., Cave sandstone deposits of the Southern Ozarks; Bull. Geol. Soc. America, vol. 17, 1907, pp. 251-256.

[16] Eureka Springs-Harrison Folio, U. S. Geol. Survey, Folio No. 202, 1916.

The possibility has been considered that the Everton limestone once extended farther north than now and that a widespread emergence, which permitted the carving on the surface of that limestone of the visible relief in Arkansas, also was responsible for the removal of the northern fringes of the formation, thus reducing its actual area. Were this the case, it is extremely likely that worn fragments of the limestone, enclosed in the sand, at or near the upper Everton horizon, would presist beyond the present limit of the limestone. Nothing of the sort has been found. Moreover, no evidence of an erosion break has ever been reported within the sandstone to the north in Iowa, Illinois, Wisconsin, or Minnesota. This, however, need not be surprising, in any case, since the sand is so little consolidated as to preserve but poorly any hills and valleys carved in it, and to fail entirely in the formation of a conglomerate, so that any erosion surface made on it would be detected with difficulty. The absence, then, of any recognized unconformity within the sandstone would not serve as a very convincing argument against the possible wide extent of emergence, at the close of Everton time.

On the other hand, the apparent decrease in the relief on the surface of the Everton limestone northward; the lack of a conglomerate at this horizon, north of Ste. Genevieve; and the lack of limestone fragments at this horizon, beyond the actual limits of the limestone border, all point to a decreasing emergence to the north, and suggest that this land area in mid-St. Peter time was local to south Missouri and north Arkansas. This is in conformity with the well-known positive character of the Ozark element, in the Paleozoic sediments of which there are a great number of unconformities and abundance of shallow water sediments, even in the marine phases of which suncracks indicate local very brief exposure above water, at numerous horizons.

Reference has already been made to the unconformity at the base of the Everton where that formation has been differentiated. In the area where the two formations cannot be separated, the unconformity is usually spoken of as being at the base of the St. Peter. Reasons have already been given for believing that even in this area, the equivalent of the Everton is present. If this interpretation is correct, it follows that the basal unconformity here is to be correlated with that at the base, not that at the top, of the Everton, and such is definitely the writer's interpretation. Along this erosion surface, in Warren and Montgomery counties, the local relief is considerable, over 50 feet in a quarter of a mile[17] being noted at one point. Within the area of an entire county, it is probable that the relief was at least nearly double this figure.

The St. Peter in Missouri consists of a medium-grained sandstone, extremely friable, very pure, and with well-rounded and frosted grains. Special sections will be devoted to a study of the purity and textural characteristics of the sandstone. Ripple marks are rare, but not unknown. Their scarcity is quite probably to be attributed to lack of preservation rather than to lack of formation. To this failure, the extreme purity of the sand is evidently the chief contributing factor, since burial with dissimilar material is the most favorable condition for preservation.

Much of the sandstone is very massive, both bedding and cross-bedding being poorly shown. Again the purity of the sand seems to be the chief cause of the lack of these structures. When the outcrops are viewed at a distance, a certain massive appearance of bedding can often be noted that is not visible at closer range. At other places, bedding is brought out by thin "clay" or "mud seams", some of which are actually only slightly more argillaceous phases, the sand showing a green color. Cross-bedding, while rather generally present, is nowhere steep, intricate; or on a large scale. Nothing comparable to dune cross-bedding has been noted in the formation in Missouri. There are none of the large curves, with steep slopes so characteristic of the LaPlata (White Cliff and Vermillion Cliff) sandstone of the Colorado Plateau, which seems to approach most closely to the supposed type of preserved sand dune structure, of any formation with which the writer is familiar. In fact, the St. Peter, at least in Missouri, is distinctly less cross-bedded than most of the other sandstones with which the writer has had experience, including the Roubidoux of Missouri, the Coconino of Arizona and Utah, the LaPlata of the Colorado Plateau, or the Cloverly of Wyoming.

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[17] Dake, Sand and gravel, p. 112.

It is, of course, true that in a formation as thin as the St. Peter, any dune structure, if such had ever been present, might have been largely destroyed by subsequent wave modification. Nevertheless, in many discussions concerning the origin of the St. Peter, the writer has found the very general belief that the St. Peter really does exhibit dune structure. Such a misapprehension should be corrected. In that portion of the formation studied in Missouri, cross-bedding, while present, is distinctly not of the dune type, is nowhere particularly striking, and in general is less noticeable than the true bedding (plates XXI-XXX).

In southeast Missouri, the St. Peter itself (restricted) carries limestone lenses. In Sec. 3, T.35 N., R.10 E., the following partial section was measured:

Joachim, 20 ft. well-bedded gray dolomite.
Transition, { 20 ft. massive buff sandstone.
6 ft. sandy dolomite.
St. Peter, 45 ft. massive buff sandstone, base not exposed.

It is not believed that this dolomite represents the Everton horizon, since the sandstone above it is only 20 feet thick, whereas the St. Peter, only two miles northwest of there, is at least 60 feet thick, above the Everton. It seems more probable that another dolomite lens has come in, than that the St. Peter has thinned so rapidly.

In Sec. 4, T. 35N., R. 10E., less than a mile from the last section, the following condition obtains:

4. 15 ft. gray well-bedded dolomite.
3. 5 ft. buff sandstone.
2. 10 ft. alternating sandstone and dolomite.
1. 80 ft. buff sandstone, base not exposed.

No. 4 is without a doubt the Joachim. Number 1 is probably St. Peter and Everton together, in which the Everton dolomite has pinched out. Numbers 2 and 3 are the transition beds, which everywhere in Perry and Cape Girardeau counties characterize the passage from St. Peter to Everton. Fossils were found in these transition beds in abundance in the NE.¼ NW. ¼ Sec. 19, T. 32N., R. 12E., in Cape Girardeau county. These fossils, however, are so poorly preserved that specific identifications were impossible. Three genera were distinguished as follows:

Lophospira cf. oweni.
Hormotoma sp.
Modiolodon or Modiolopsis.

They are essentially valueless for purposes of correlation, but are of interest because fossils are so rare at this horizon.

Joachim.—Next above the St. Peter beds, in Missouri, rests a slightly argillaceous gray dolomite, known as the Joachim, and everywhere in the the older reports called the First Magnesian Limestone. This formation is well developed in the north and east flank of the Ozarks in the State, but is doubtfully known on the west flank, where it is probably largely overlapped and hidden by the Carboniferous formations. So far as can be noted, there is perfect conformity between the St. Peter and Joachim. Near Pacific in one of the quarries is an appearance of slight discordance between the two, but a careful examination of the locality shows that this condition results from gently dripping cross-bedded layers, immediately below the Joachim, and is certainly not the result of folding and angular unconformity.

The appearance of conformity is strengthened by the transition layers described under the St. Peter section, and by the occurence of rounded grains of sand, of the St. Peter facies, in gradually diminishing quantity from base upward, in the Joachim. This condition, however, is not as significant as might be supposed, when the possibilities are examined. Were the St. Peter terrestrial, or were its surface emerged and eroded, before the laying down of the Joachim limestone, it is quite certain that, with a readvance of the sea over the incoherent sands, evidences of channelings would be nearly or quite obliterated; while there would be no material from which the usual basal conglomerate could be formed. Under such conditions a considerable erosion interval might occur, and still wholly escape detection. The writer knows of no reason whatever for believing that such a time did elapse before the deposition of the Joachim upon the St. Peter sand surface. The best, and about the only evidence, however, that it did not, is the interbedding of the transition layers in southeast Missouri. And this is only suggestive, by no means conclusive.

The Joachim varies rapidly in thickness, from over 100 feet to less than 5 feet. Its contact with the St. Peter has been followed with much care, and is known to be a very even one. Such variations as occur result from its uneven upper surface, which underwent considerable erosion before the overlying Plattin was laid down. The presence of an erosion break at this horizon has already been made known[18], but the writer secured very striking evidence of it, not before recorded. At Crystal City, the Joachim is over 100 feet thick. Less than 5 miles southeast, in Sec. 6, T. 39N., R. 7E., the overlying Plattin is separated from the St. Peter by less than 5 feet of intervening beds. Farther southeast, the Joachim again becomes thicker. There seems to be no possibility whatever that this is the result of faulting.

A similar thinning of the Joachim has been suspected at Dutchtown, in Cape Girardeau county. Here, however, the evidence is less clear, as the outcrops are separated by a low flat area which might possibly conceal a fault, and there may be some doubt as to the correlation of the beds involved. Beds lying 10 feet above the top of the St. Peter, but with the interval covered, have been correlated with the Plattin, on the basis of their lithologic character. Imperfect fossils discovered in these beds are similar in general aspect to those reported at the Joachim-St. Peter contact (p. 26), and have been identified as follows:

Modiolodon cf. oviformis.
Primitia cf. celata.
Leperditia sp.
Lophospira cf. oweni.

The poor preservation has rendered exact identifications impossible, and the list is little more than indicative of Middle Ordovician.

If the beds are Plattin, the conditions constitute additional evidence of unconformity between Joachim and Plattin. If they are Joachim, the fact is of interest as indicating a new fossil locality for this extremely barren formation. The outcrops are sufficiently isolated so that it is extremely difficult to get additional evidence.

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[18] Buckley, E. R., Geology of the disseminated lead deposits of St. Francois and Washington Counties; Missouri Bur. Geol. and Mines, 2nd ser., vol. IX., p. 63. Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, 1911, p. 466.

The fact that fossils are very rare in the Joachim limestone should be borne in mind when considering the scarcity of fossils in the St. Peter sandstone below. So far as the writer has been able to discover, the only fossil previously reported from the formation in Missouri is a small *Cythere*[19], presumably our present genus *Leperditia.* Shumard concludes that the species is distinct from *Cythere* (*Leperditia*) *sublaevis,* found higher in the column, but does not attempt to identify the species. Since the genus has a large vertical range it has little or no diagnostic value. Bassler[20] lists *Cythere* (*Leperditia*) *sublaevis* (Shumard) from the Joachim of Missouri, but since the species has not been found elsewhere, it is of no assistance in correlation with other regions. The fossils found by the writer in the St. Peter-Joachim transition beds have already been listed on a previous page (p. 26). Reference has also just been made to fossils collected near Dutchtown, in Cape Girardeau county, which are either Joachim or Plattin (p. 27) but which are too poorly preserved to make possible any satisfactory conclusion.

Plattin.

The Plattin, which unconformably overlies the Joachim in Missouri, is especially well developed on the east and north flank of the Ozarks, but if present on the western slope, is completely overlapped and hidden by the Carboniferous rocks. This formation, known in the older reports as the Birds Eye, Black River, and Lower Trenton, consists of a compact, fine-grained, bluish-gray limestone, ranging in thickness up to a maximum probably not greatly in excess of 200 feet.

According to Ulrich the Plattin is equivalent to, or at least contains the Lowville,[21] at a point 6 miles west of Ste. Genevieve. He does not list any Lowville fossils, however. Older reports on the state[22] list a few fossils from this horizon, which is supposed to range from Birds Eye through Black River into Lower Trenton. Judging by the nature of the lists, and the very meager descriptions of the lithologic character, however, it is probable that the earlier workers have not always discriminated between these horizons in making their collections.

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[19] Shumard, B. F., Reports on the Geological Survey of the State of Missouri, 1855-1871, p. 308.

[20] Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils; U. S. Nat. Mus. Bull. No. 92.

[21] Ulrich, E. O., Revision, p. 466.

In Jefferson county, the Birds Eye is said to contain *Cythere* (*Leperditia*) *sublaevis* and a filiform coral similar to a *Syringopora* from the Birds Eye of Kentucky. The *Leperditia sublaevis* is said by Bassler to be limited to the Joachim. Quite probably the exact contact was not recognized in the field. Since *Syringopora*, as now delimited, does not range so low, it is evident that the form so identified was something else. The Paleontological volumes of the Missouri Survey do not figure or describe any *Syringopora* from this horizon, so it is not possible to determine what form was meant. It is quite possible that the form found was *Phytopsis tubulosa*, a characteristic Lowville form, or even more possibly *Tetradium cellulosum*, also a good Lowville index fossil. However, there can be no assurance that this interpretation is correct.

The so-called Black River horizon is said to contain *Gonioceras anceps*, a characteristic Black River form, and *Ormoceras* (*Actinoceras*) *tenuifilum*.

In Perry county, no faunas are described from the Birds Eye and Black River, but the Trenton is said to contain *Subulites elongatus*, *Strophomena filitexta* (*incurvata*), *Leptaena* (*Plectambonites*) *sericea*, *Orthis* (*Hebertella*) *occidentalis*, *Orthis* (*Pianodema*) *subaequata*, and *Rhynchonella* (*Rhynchotrema*) *capax*. With Trenton forms there are here mingled forms which, if correctly identified, are clearly Fernvale. It is, therefore, believed that this formation probably here rests, due to pre-Fernvale erosion, on beds older than Kimmswick. As a result collections made apparently without due regard to horizons contained a mixed fauna. Faulting, which is also extensive in this county, may be responsible for some of the uncertainty.

In Cape Girardeau county, the Black River is reported to contain *Stictopora ramosa*. Since this old genus of bryozoa has been split up into several genera and many species, ranging from

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[22] Reports on the Geological Survey of the State of Missouri, 1855-1871, pp. 306-307, 297-298, 282-284, 265-267, 49-52.

Stones River through Trenton at least, it is quite impossible to determine what form was found. Black River faunas are not reported from the county. The Trenton is said to contain *Strophomena filitexta* (*incurvata*), *Leptaena* (*Plectambonites*) *sericea*, and *Orthis* (*Pianodema*) *subaequata*, forms which range at least from Stones River into Black River, and are therefore not sufficiently restricted to be of much value in determining whether the Lowville is present or not.

In Warren county, the Black River is reported to yield *Cythere* sp., *Murchisonia* sp., *Leptaena* sp., *Leptaena deltoidea* (?) and *Orthis* sp. None of these genera, of which species are not given, are sufficiently restricted to be of any value. Moreover, the genera have been so split up and restricted that nothing can be done with them, unless species are given. The *Leptaena deltoidea* (?) is questioned by the author, and is therefore of little significance. It is probably either *Rafinesquina deltoidea* or *R. minnesotensis*. In the same locality, the Lower Trenton carries *Orthis* (*Pianodema*) *subaequata*, a form that ranges as low as Stones River, and *Subulites elongatus*, a characteristic Trenton fossil.

Branson[23] describes an Ordovician fauna from residual cherts, in north Missouri. Unfortunately, because of its residual character, it is not possible to resolve it into exact stratigraphic horizons. Nevertheless, it is of much interest.

Fauna of the residual cherts of Lincoln County.

	Range.
Hindia parva? Ulrich	Bl. R.
Streptelasma corniculum? Hall	T.
Lichenaria typa? W. & S	Bl. R.
Rhinodictya sp. undet	
Dalmanella (Pianodema) subaequata Conrad	St. R.-Bl. R.
Lingula sp. undet	
Dalmanella testudinaria Dalman	St. R.-Bl. R.
Orthis tricenaria Conrad	St. R.-Bl. R.
Strophomena incurvata Shepard	St. R.-Bl. R.
Zygospira recurvirostris Hall	Bl. R.-T.
Zygospira nicolleti W. & S	Bl. R.
Ctenodonta auburnensis n. sp	a.
Ctenodonta costata n. sp	a.
Ctenodonta medialis Ulrich	Bl. R.
Ctenodonta nasuta Hall	Bl. R.
Ctenodonta oviformis Ulrich	T.
Ctenodonta n. sp	

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[23] Branson, E. B., The fauna of the residuary Auburn chert of Lincoln County, Missouri; Trans. Acad. of Sci. of St. Louis, vol. 18, 1908-9, pp. 39-52.

	Range.
Cyrtodonta sp. undet	
Goniophora carinata Conrad	T.
Modiolodon subrhomboideus n. sp	
Modiolopsis expansa n. sp	a.
Modiolopsis sp. undet	
Parallelodus obliquus n. gen. & sp	a.
Psiloconcha ? sp. undet	
Rhytima sp. undet	
Sphenolium sp. undet	
Whiteavesia subcarinata Ulrich	T.
Archinacella patelliformis Hall	Bl. R.-Mays,
Archinacella sp. undet	
Carinaropsis actua U. & S	Bl. R.
Cataschisma typa n. gen. & sp	a.
Carinaropsis phaleria Sardeson	Bl. R.
Conradella (Phragmolites) fimbriata U. & S	Bl. R.
Cyrtolites retrorsus Ulrich	T.
Bellerophon capax Ulrich	Mays
Bucania halli U. & S	Low.-Bl. R.
Eotomaria dryope Billings	Bl. R.
Helcionopsis sp. undet	
Helicotoma missouriensis n. sp	a.
Helicotoma tennesseensis Safford	St. R.
Holopea insignis U. & S	Bl. R.
Hormotoma gracilis v. sublaxa Hall	a.
Hormotoma fasciata n. sp	a.
Hormotoma latiangularis n. sp	a.
Liospira micula Hall	T.-Rich.
Liospira progne Billings	St. R.-T.
Liospira n. sp	
Lophospira perangulata Hall	St. R.-Bl. R.
Lophospira fillmorensis Ulrich	Low.-Bl. R.
Lophospira obliquua Ulrich	T.
Lophospira oweni U. & S	Low.-Bl. R.
Lophospira saffordi Ulrich	T.
Pterotheca expansa Emmons	Bl. R.
Pterotheca sp. undet	
Strophostylus textilis U. & S	Bl. R.-T.
Cyrtoceras (Zitteloceras) billingsi Salter	Bl. R.
Cyrtoceras sp. undet	
Orthoceras (Spyroceras) bilineatum Hall	Bl. R.-T.
Orthoceras sociale Hall	Rich
Bathyurus spiniger Hall	Bl. R.
Bumastus trentonensis Emmons	T.
Ceraurus pleurexanthemus Green	Bl. R.-T.
Isotelus iowensis Owen	Rich.
Pterygometopus lincolnensis n. sp	a.
Pterygometopus intermedius Clarke	Bl. R.
Ptychopygo sp. undet	
Primitia 2 n. sp	
Technophorus bellistriatus n. sp	a.

The list is made up overwhelmingly of Black River forms. By Bassler[24] the Auburn chert is correlated with the Decorah, but it probably also includes the equivalent of part of the Platteville, since it also contains many species characteristic of that formation. It is certainly the Plattin of regions elsewhere in the state. The fact that the fauna is derived from a chert suggests that the parent rock was a limestone, and not the usual Decorah shale facies. The shale facies of the Decorah is reported by Weller* to be locally developed in Ste. Genevieve county.

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[24] Bassler, R. S., Biliographic index of American Ordovician and Silurian fossils; Bull. 92, U. S. Nat. Mus., 1915.

Rowley[25] gives a list of fossils from the undivided Plattin and Kimmswick of Pike county.

"Trenton" fossils from Pike County.

	Range.
Halysites catenulatus	T.-Cob.
Receptaculites globularis (Ischadites iowensis)	T.
Receptaculites oweni	Bl. R.-T.
Columnaria alveolata	St. R.-Rich.
Streptelasma corniculum	T.
Plectambonites sericeus	Bl. R. Rich.
Platystrophia lynx-var	T.-Rich.
Orthis tricenaria	St. R.-Bl. R.
Dinorthis pectinella	Bl. R.-T.
Dalmanella testudinaria	Bl. R.-Rich.
Dalmanella (Pianodema) subaequata	St. R.-Bl. R.
Orthis perverta	?
Rhynchotrema increbescens	T.
Rafinesquina alternata	T.-Rich.
Strophomena filitexta (incurvata or neglecta)	St. R.-Rich.
Strophomena (Rafinesquina) deltoidea	T.
Zygospira recurvirostris	Bl. R.-T.
Bellerophon bilobatus (Sinuites cancellatus)	T.-Rich.
Fusispira ventricosa	T.
Helicotoma planulata	Bl. R.
Maclurea (Maclurites) magna (?)	Chazy.
Murchisonia (Hormotoma) gracilis	T.-Rich.
Murchisonia (Lophospira) bicincta	St. R.-Rich.
Murchisonis (Hormotoma) bellacincta	T.
Raphistoma lenticulare (Liospira vitruvia)	Bl. R.-Rich.
Subulites elongatus	T.
Trochonema umbilicatum	Bl. R.-T.
Bucania punctifrons	T.
Illaenus taurus (americanus)	T.
Murchisonia (Hormotoma) major	T.

As is to be expected, Black River and Trenton forms are mixed in this list. One of the particularly interesting features is the occurrence in the Trenton of the chain coral *Halysites catenulatus*. So far as known, Rowley is the first to describe this form from beds as old as Trenton, and the only one to describe it from these beds as far south as Missouri. The above evidence is alone quite insufficient to warrant any conclusion as to the presence of the Lowville equivalent, in the Plattin; though no data are found that would not permit of interpreting it as being present. The Plattin may, then, be interpreted as essentially of Black River age; probably, judging by its thickness as compared with the type Black River, including Lowville; though definite evidence is lacking on this point.

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*Unpublished manuscript.

[25] Rowley, R. R., Geology of Pike County; Missouri Bur. Geol. and Mines, 2nd ser., vol. VIII, 1907, p. 15.

Kimmswick.

This formation, which has its best development on the east flank of the Ozarks, and which is known well north into Pike county, is either not present on the western border, or else is so overlapped by later sediments as to fail of exposure. By the older writers it has been termed the Receptaculite limestone, or the Upper Trenton. It consists chiefly of very crystalline limestone ranging from drab to light gray, or almost white, and varying in thickness, averaging perhaps 100 feet or less. The writer has seen no physical evidence of a break at the contact with the Plattin below, but Weller* reports that the very patchy development of the Decorah shale in Ste. Genevieve county results from pre-Kimmswick erosion. Because of the great abundance of the so-called "sunflower coral," *Receptaculites*, the general tendency has been to correlate this formation with the Galena of the Upper Mississippi Valley. Ulrich claims, however, that the Kimmswick is late Black River, and that in Pike and Lincoln counties, Missouri, the true Galena is found resting on the Kimmswick.[26]

The older reports of the Missouri Survey[27] list a few fossils from this formation. The list from Jefferson county is as follows: *Receptaculites*, *Illaenus*, *Asaphus* (*Isoletus*), and *Orthis* (*Platystrophia*) *lynx*. Above this is about 10 feet of blue limestone carrying *Leptaena* (*Plectambonites*) *sericea*, *Orthis* (*Hebertella*) *occidentalis*, and *Rhynchonella* (*Rhynchotrema*) *capax*. The higher beds are clearly Fernvale.

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*Unpublished manuscript.

[26] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, 1911, p. 524.

[27] Reports of the Geological Survey of the State of Missouri, 1855-1871, pp. 297.

From Cape Girardeau county, the following forms are reported; *Asaphus* (*Isotelus*) *gigas*, *Rhynchonella* (*Rhynchotrema*) *capax*, *Orthis* (*Platystrophia*) *lynx*, *Strophomena* (*Rafinesquina*) *alternata*, and *Strophomena* (*Rafinesquina*) *deltoidea*. Some of these forms are so characteristically Fernvale that it is evident the worker in the field failed to discriminate between the two horizons, and mixed the faunas.

In Warren county, the same horizon is reported to yield *Orthis* (*Dalmanella*) *testudinaria*.

In the above faunas, there is certainly a representative of the Fernvale, but there may also be noted indications of a lower horizon, which is undoubtedly the true Kimmswick. Ulrich reports very positive evidence of an unconformity between the two, with the Fernvale resting on various horizons of the Kimmswick.[28] The earlier workers in the field, except at occasional localitities, failed to note that two horizons were represented.

The data here given is certainly not very conclusive, but indicates, in addition to the presence of the Fernvale, a horizon, the Kimmswick, which cannot be older than Black River, nor probably younger than the Trenton. So far as the writer can discover, Ulrich has presented scant fossil evidence for the exact age of the Kimmswick of Missouri. In the reference above cited, he calls attention, incidentally to *Receptaculites oweni*, and still higher in the formation, to *Echinosphaerites* and *Comarocystites*. Bassler[29] lists the former as ranging through Black River and Trenton, and the latter as Middle Ordovician. If, however, Ulrich's interpretation be correct, that the Galena rests on the Kimmswick, in northern Missouri, then the latter is either Black River or early Trenton. This point will be referred to again, under the discussion of the stratigraphy of Iowa and other northern states (pp. 79-81, 89-92, 107-108, 119-123).

Swallow[30] gives a list of Trenton fossils from Missouri, but a study of the list shows that Plattin, Kimmswick and Fernvale forms have been included, and since there are no data as to localities or sections, the list is of very little value. It is presented, in part, below, with the best possible interpretation of the old names given, and the significance of the forms.

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[28] Ulrich, E. O., Revision; p. 309.

[29] Bassler, R. S., Index.

[30] Swallow, G. C., The First and Second Annual Report of the Geological Survey of Missouri, 1855, p. 220.

Swallow's List of "Trenton" Fossils.

	Range.
Homocrinus (sp. undet)	
Streptelasma corniculum Hall	**T.**
Receptaculites (Coscinopora) sulcata Owen, (Receptaculites oweni)	**Bl. R.-T.**
Ptylodictya (Pachydictya) acuta Hall	**T.**
Ptylodictya (Escharopora) recta Hall	**T.**
Orthis (Platystrophia) lynx Eichwald	**M. & U. Ord.**
Orthis disparilla Conrad (O. tricenaria)	**St. R.-Bl. R.**
Orthis tricenaria Conrad	**St. R.-Bl. R.**
Orthis (Pianodema) subaequata Conrad	**St. R.-Bl. R.**
Orthis (Dinorthis) pectinella Hall	**U. Bl. R.-Early T.**
Orthis (Dalmanella) testudinaria (?) Dalman	**M.-U. Ord.**
Leptaena (Plectambonites) sericea Sowerby	**M.-U. Urd.**
Leptaena (Rafinesquina) deltoidea Conrad	**T.**
Laptaena (Rafinesquina) alternata Conrad	**T.-Rich.**
Leptaena filitexta Hall (Strophomena incurvata)	**St. R.-Bl. R.**
Atrypa (Zygospira) recurvirostris Hall	**Bl. R.-T.**
Atrypa increbescens Hall (Rhynchotrema capax & R. inaequivalve)	**T.-Rich.**
Cardiomorpha (Cuneamya) vetusta Hall	**T.**
Edmondia (Whitella) subtruncata Hall	**T.**
Murchisonia (Hormotoma) bellacincta Hall & H. trentonensis	**T.**
Murchisonia (Lophospira) bicincta Hall	**St. R.-Rich.**
Murchisonia (Hormotoma) gracilis Hall	**T.-Rich.**
Subulites elongatus Conrad	**T.**
Pleurotomaria (?) lenticularis Sowerby	**Valueless**
Pleurotomaria (Trochonema) umbilicata Hall	**Bl. R.-T.**
Pleurotomaria (Liospira) subtilistriata Hall	**T.**
Bellerophon bilobatus Sowerby	**?**
Orthoceras junceum Hall	**Bl. R.-T.**
Orthoceras vertebrale Hall (Cycloceras olorus)	**Bl. R. T.**
Illaenus crassicauda (?) Wahl (Bumastus erastusi)	**Chazy.**
Dalmanites (Pterygometopus) callicephalus Hall	**T.**
Cheirurus (Ceraurus) pleurexanthemus Green	**Bl. R.-T.**
Asaphus (Isotelus) iowensis Owen	**Rich.**

These fossils are supposed to come from horizons higher than the Birds Eye, and are reported to include faunas from both Black River and Trenton. There seems to be no other interpretation if the identifications are correct. It is practically certain that the list includes forms from Plattin, Kimmswick and Fernvale.

Richmond.

The Fernvale (Richmond) has been described by Ulrich[31] as resting on the eroded surface of various horizons of the Kimmswick. Weller[32] also calls attention to the fact that in St. Louis and Jefferson counties, the true Richmond (Fernvale) limestone, about two feet in thickness, transgress several horizons of the Kimmswick, in a way that can be interpreted only as unconformity. In these localities he reports from 4 to 30 feet of Maquoketa shale overlying the Fernvale limestone. Neither writer gives detailed descriptions of the formation, nor can any descriptions found in the older reports be sufficiently analyzed to discriminate with certainty between this and older horizons, over most of the area. A few species of Richmond fossils are already listed under the description of the Kimmswick (p. 33), and these must certainly have been collected from the Fernvale, though the earlier workers clearly mixed the faunas.

At a single locality, the writer collected a small fauna of Fernvale age from a two-foot bed of medium-grained slabby bluish-gray limestone. The ledge was exposed in the vicinity of a fault, and was nowhere seen in contact with the subjacent beds, so that its exact relations are not known. The fauna clearly establishes, however, the presence of Fernvale, in that locality. The collection was made from the W. ½ Sec. 31, T. 36. N., R. 12. E., along the Mississippi River bluffs, near Menfro, Perry county, Missouri.

Richmond fossils near Menfro, Perry County.

Strophomena rugosa (planumbona) (Rafinesque).
Dinorthis subquadrata (Hall).
Rhynchotrema (?) anticostiense (Billings).
Hebertella occidentalis (Hall).
Gyronema sp.
A gastropod of the type of Subulites or Fusispira.
At least four species of undetermined bryozoans, very fragmentary, apparently including Bythopera and Hemiphragma.

The "Hudson River" in Pike county is reported by Rowley[33] to consist of about 100 feet of light blue sandy shale from which he collected the following fossils:

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[31] Ulrich, E. O., Revision, p 209.

[32] Weller, Stuart, The pre-Richmond unconformity in the Mississippi Valley; Jour. Geol., vol. 15, 1907, pp. 519-525.

[33] Rowley, R. R., Geology of Pike County; Mo. Bur. Geol. and Mines, 2nd ser., vol. VIII, 1907.

"Hudson River Shale" fauna from Pike County.	**Range.**
Plectambonites sericeus	Bl. R.-Rich.
Platystrophia acutilirata	Rich.
Dinorthis subquadrata?	Rich.
Hebertella sinuata	Mays.-Rich.
Dalmanella testudinaria	Bl. R.-Rich.
Rhynchotrema capax	Rich.
Strophomena filitexta (incurvata)	St. R.-Bl. R.
Strophomena planumbona	Rich.
Rafinesquina alternata	T.-Rich.
Zygospira recurvirostris	Bl. R.-T.
Murchisonia (Hormotoma) gracilis	T.-Rich.
Murchisonia (Lophospira) bicincta	St. R.-Rich.
Asaphus megistos (Isotelus maximus)	T.-Rich.
Asaphus (Isotelus) gigas	Bl. R.-Rich.
Calymene callicephala?	

Among several typical Richmond forms are also given several that range into Richmond from lower horizons, and one, *Strophomena filitexta* (*incurvata*) commonly not found above Black River. Without much question, this shale is the Maquoketa.

According to Shumard[34] the "Hudson River" also has a notable development in Cape Girardeau county, consisting of an upper shale member about 45 feet thick, a middle sandstone about 100 feet thick, and a lower shale bed 40 to 60 feet thick. This lower member yielded *Asaphus* (*Isotelus*) *gigas*, *Strophomena* (*Rafinesquina*) *deltoidea*, *Leptaena* (*Plectambonites*) *sericea*, *Rhynchonella* (*Rhynchotrema*) *capax*, and *Turbo* (*Cyclonema*) *bilix*. This is essentially a Richmond assemblage, and the formation is correlated with the Maquoketa.

The thickness given above is probably excessive. The middle sandstone was formerly known as the Cape Girardeau, and is now called the Thebes.[35] It is an impure shaly sandstone (silica 87 per cent) about 75 feet thick, and is of considerable interest, as a coarser sandy phase of the Richmond, for which no immediate source is apparent. It is also reported in Ste. Genevieve county, and is correlated with the Thebes of Illinois. Its significance will be discussed more fully in sections dealing with Illinois, in which state it has been more carefully studied.

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[34] Shumard, B. F., Reports on the Geological Survey of the State of Missouri, 1855-1871, pp. 264-265.

[35] Dake, C. L., Sand and gravel resources of Missouri; Mo. Bur. Geol. and Mines, 2nd ser., vol. 15, 1918, p. 172.

Keyes[36] describes an area in Lincoln county, in which beds from Jefferson City to Maquoketa outcrop. To the Jefferson City he applies the term Winfield limestone; to the St. Peter, Cap au Gres sandstone; to the Joachim, Folley limestone; to the Plattin, Bryant limestone; to the Kimmswick, McCune limestone; and to the Maquoketa, Buffalo shale.

ARKANSAS.

In Arkansas, there are two important regions that expose rocks of the general age discussed in this paper. The most significant one is the Ozark area in the northwestern corner of the state, near the Missouri-Oklahoma line, in the region of the Fayetteville and Eureka-Harrison folios. The other and less known region is in the Ouachita Uplift, farther south. The former will be considered first.

Stratigraphy of the Arkansas Ozarks.

The most thorough and recent study of the stratigraphy of this region is summed up in the Eureka Springs-Harrison folio.[37] Other studies are presented in Professional Paper 24 and the Fayetteville Folio, No. 119. From these reports, but chiefly from the first, the following information is summarized:

Cotter.—The oldest bed described is the Cotter formation. The writer, however, has noted the presence of the Jefferson City at the state line, on the North Fork of White River, some distance farther east. It is not believed that the Roubidoux, the oldest of the Beekmantown formations, outcrops anywhere in northern Arkansas, unless it may happen that it is brought up locally by small anticlines. In working along the Missouri-Arkansas line, the writer found that on Current River, the Roubidoux passed below the Jefferson City about 8 miles north of the boundary; on Eleven Point River, about 4 miles north; on Spring River, about 5 miles; and on the North Fork of White River, about 3 miles. With the average dip of the formations to the south, about 20-30 feet to the mile, and with the considerable depth of dissection that obtains, it is doubtful whether the Jefferson City occupies more than very small areas along these streams, and quite probably is nowhere exposed at the state line, except on North Fork of White River.

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[36] Keyes, C. R., Some geological formations of the Cap au Gres uplift; Proc. Iowa Acad. Sci., vol. V, 1897, pp. 58-63.

[37] U. S. Geol. Survey, Folio 202, 1916.

The Cotter formation reaches a maximum thickness of about 500 feet and was included in the Yellville as first delimited. Yellville seems to have been variously used to include Cotter Powell, and possibly some Jefferson City. Later the Yellville was restricted to the Powell, and the Cotter was included in the Jefferson City. The Cotter consists of cherty dolomite, with thin layers of sandstone and a very few laminae of shale. Its upper surface was somewhat eroded, before the Powell was laid down upon it. The formation has yielded the following fauna:

Fauna of the Cotter.

*Cryptozoon minnesotense Winchell.
Tryblidium angustum Ulrich.
Sinuites ? cf. S. rossi Collie. .
Maclurea ? aff. M. affinis Billings.
Ceratopea keitni var. Ulrich.
*Eccyliopterus planidorsalis Ulrich.
Eccyliopterus planibasilis Ulrich.
*Orospira bigranosa Ulrich.
*Lophomena angulare Ulrich.
Lophomena striatellum Ulrich.
*Lophomena basistriatum Ulrich.
*Lophomena peccatonica (Sardeson).
*Hormotoma cf. H. artemesia (Billings).
*Hormotoma sp., small, very slender.
Liospira subplana (Shumard).
Plethospira n. sp.
*Cameroceras consuetum (Sardeson).
Cameroceras sp.
Tarphyceras cf. T. seelyi (Whitfield).
Pycnoceras complanatus (Shumard).

The forms starred in the above list, about half the total, are said to occur also in the Shakopee of the Iowa-Minnesota-Wisconsin area. The Cotter is also correlated, in the folio, with the middle and upper Beekmantown of the New York region.

Powell.—The Powell limestone rests on the eroded surface of the Cotter dolomite. It is the top of the original Yellville, and identical with Yellville as restricted by Ulrich in his "Revision of the Paleozoic systems." It reaches a maximum known thickness of 200 feet. Conglomeratic at the base, the formation consists mostly of slightly magnesian limestone, with a few thin beds of shale. The following fauna has been collected, mostly from cherty beds near the middle of the formation:

Fauna of the Powell.

Deltatreta cf. D. electra (Billings).
Syntrophia ? (new subgenus of) cf. S. palmata and S. campbelli Walcott.
Scenella sp.
Maclurea ? cf. M. sordida and M. matutina Hall.
Maclurea aff. M. crenulata Billings.
Lophospira cf. L. carinifera (Shumard).
Lophonema ? yellvillensis Ulrich.
Liospira canadensis (Billings).
Hormotoma exactus (Sardeson).
Cameroceras cf. C. montrealensis (Billings).
Cameroceras n. sp., large.
Protocycloceras lamarki (Billings).
Cyrtoceras ? confertissimum Whitfield.
Tarphyceras cf. T. seelyi (Whitfield).
Tarphyceras cf. T. clarkei Ruedemann.
Deltoceras ? (probably new genus).
Asaphus sp.
Bolbocephalus cf. B. seelyi Whitfield.
Bathyurus cf. B. conicus and B. nero Billings.
Clelandia (Harrisia) cf. C. parabola Cleland.

The authors state that a few of these species are found in the Shakopee, but suggest that the Powell corresponds only to the upper part of that formation. In another place[38] Ulrich calls attention to the general contemporaneity of the Powell with the Fort Cassin of the New York Beekmantown. He also refers, however, to basal beds that carry a slightly older Phyllograptus zone, which he describes as "the only known occurrence of the Phyllograptus fauna in American interior rocks." He lists *Phyllograptus illicifolus*, *P. angustifolis*, *Didymograptus bifidus*, and *D. amplus*. With these are associated two orthid brachiopods related to *Dalmanella wemplei* and an *Asphus* related to *A. canalis*. These are below the Fort Cassin. Above this zone comes a bed which yields *Plethospira cassina*, *Subulites obesus*, and *Eurystomites kellogi*, a typical Fort Cassin assemblage. The middle horizon is also said to yield two species of *Turritoma*, *Coelocaulus sp.*, *Hormotoma sp.* (*cf. Murchisonia argylensis*) (Sardeson), *Helicotoma sp.*, cf. *H. peccatonica* Sardeson and *Isochilina seelyi?*

The highest beds of the formation, at Black Rock, are reported to carry a fauna of undescribed sponges and bryozoa, with *Dendrograptus flexuosus* and a small *Didymograptus bifidus*. While not very definitely located in the column, this horizon is tentatively assigned by Ulrich to Division E of the New York Beekmantown.

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[38] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, 1911, pp. 667-670.

Everton.—This formation rests unconformably on the surface of the Powell. The evidence of unconformity consists largely of fragments of chert and limestone derived from the older formations, though at certain favorable localities the uneven contact can be clearly seen. The formation, which reaches a maximum of about 125 feet, carries locally, at the base, the Sneeds limestone lentil, above which is the Kings River sandstone member, and an upper limestone.

The Sneeds limestone lentil, which is a local phase, rests unconformably on and contains fragments of the Powell formation. It is described as a hard sandy magnesian limestone, in places reaching a thickness of 50 feet. The Kings River sandstone member, which is of variable thickness up to at least 40 feet, consists of a white sandstone made up of well-rounded quartz grains, very pure, ranging from friable to quartzitic, and described as "saccharoidal". It is said to be entirely indistinguishable from the St. Peter on lithologic grounds alone. In fact, it has been referred to as the Lower St. Peter.[39] The upper limestone member consists of a complex of interbedded sandstone and limestone, the latter making up on the average about 60 per cent. The alternating beds are thin, and the sandstones are in all respects similar to the Kings River member below or the St. Peter above. The intricate interbedding of the sandstone and limestone can only be appreciated by studying a detailed section, such as the one below, reproduced from the Eureka-Harrison Folio.

Section of Everton on Buffalo Fork, Ark.

	Ft.	In.
Compact dove-colored limestone	20	0
Friable massive saccharoidal sandstone	10	0
Compact dove-colored limestone	1	0
Saccharoidal sandstone		8
Compact dove-colored laminated limestone	2	0
Saccharoidal sandstone	1	0
Compact dove-colored limestone	0	6
Saccharoidal sandstone	1	0
Laminated compact dove-colored limestone	1	6
Saccharoidal sandstone	5	6
Compact dove-colored limestone		6

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[39] Purdue, A. M., Cave sandstone deposits of the southern Ozarks; Bull. Geol. Soc. America, vol. 17, 1907, pp. 251-256.

	Ft.	In.
Sandy limestone		6
Compact dove-colored limestone		6
Sandstone grading into limestone above	1	6
Laminated compact dove-colored limestone		6
Sacchariodal sandstone	3	6
Compact dove-colored limestone, with sandstone	2	6
Saccharoidal sandstone	1	0
Compact dove-colored limestone		10
Laminated saccharoidal sandstone	10	0

Base not exposed.

Local conglomerates, marking local unconformities, are reported at the top of the Sneeds limestone lentil, and also at the top of the Kings River sandstone member.

The entire formation is believed to be more closely related to the St. Peter above, than to the Powell below, partly because it is lithologically much more like the St. Peter than like lower horizons, especially in the presence of the so-called typical rounded St. Peter grains; and partly on the basis of the faunas it has yielded. These are listed herewith.

Faunas of the Everton formation.

Sneeds limestone lentil.

Lophospira cf. L. gregaria (Billings) and perangulata Hall.
Lophospira ? sp., low spired, with sharp peripheral keel, resembling L. abnormis.
Turritoma n. sp.
Hormotoma aff. H. gracilis.
Aparchites sp. undet.
Bathyurus ? sp.

Upper limestone member.

Monotrypa n. sp.
Ctenodonta novica (Sardeson).
Raphistomina n. sp., same as found in Jasper limestone.
Lophospira sp., low spired, found also in Sneeds limestone lentil.
Lophospira sp., resembling L. conradana Ulrich.
Fusispira ? sp., height less than 10 mm.
Isochilina sp. 1, surface punctate.
Isochilina sp. 2, surface smooth.
Leperditia ? sp.
Primitia cf. P. logani Jones.

Of these fossils, one species is reported from the St. Peter' elsewhere; one is found both in the Sneeds limestone and the upper limestone; and one occurs in the Jasper limestone. As a whole it is not closely related to either the Beekmantown or the known Chazy, but apparently more closely resembles the latter than the former.

The presence of marine fossils at two horizons, near base and top, and the intricate interbedding of limestones with the sandstones, makes it obvious that the whole formation was laid down in the sea. No fossils, however, are found in the sandstone beds, which are apparently quite as barren as the overlying St. Peter in that respect.

St. Peter.—This formation, known in the older reports as the Key sandstone, rests on the much-eroded surface of the Everton. The thickness varies greatly, with a maximum of about 150 feet, the variation being caused not only by the unconformity at its base, but by the erosion of its upper beds, which are overlain by strata as late as Devonian, or even Mississippian. It consists of the familiar massive, incoherent, white to buff very pure quartz sand, of well-rounded grains. Fine lamination and cross-bedding are mentioned, but nothing which could be interpreted as dune structure is described. Reference is made to ripple marks, but the type of ripple is not indicated. At one point, a foot of limestone is reported in the formation 40 feet below the top.

Ulrich[40] states that the Everton grades up without break into the St. Peter, but in view of Purdue's statement[41] that there is a very pronounced relief on the surface of the Everton, and in view of the chert congolmerate in the base of the formation, derived from the older rocks, as described in the Eureka-Harrison folio, it must surely be admitted that there was at least local emergence and erosion, between the laying down of the two formations. The writer has already presented (pp. 22-24) his own evidence for believing that this unconformity was local, and died out northward into continuity of sedimentation.

No diagnostic fossils are described from the St. Peter in Arkansas. Scolithus and fucoidal markings are reported by Adams[42].

Joachim.—This is the lowest part of the old Izard formation. It rests with apparent conformity on the St. Peter, into which it appears to grade. The formation consists of fine-grained gray magnesian limestone, with a variable admixture of rounded sand grains. Calcareous sandstones several feet thick are interbedded. The maximum thickness is about 100 feet.

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[40] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, 1911, pp. 529 and 542.

[41] Purdue, A. M., Bull. Geol. Soc. America, vol. 17, pp. 251-256.

[42] Adams, G. I., Zinc and lead deposits of northern Arkansas; U. S. Geol. Survey, Prof. Paper No. 24, 1904, p. 21.

The only fossil found in the formation in Arkansas is *Psiloconcha senecta* (Sardeson) which occurs near the base of the Joachim, and which also occurs in the St. Peter of Minnesota.

Jasper.—The Jasper limestone rests with slightly irregular contact on the Joachim, though no other evidence of unconformity is apparent. It consists of a variable thickness, not exceeding 50 feet, of gray compact limestone with interbedded sandstones. The lower member of 20 feet is more sandy, the sandstone layers ranging up to two feet thick, separated by thin limestone beds. The upper portion is much less sandy. The sands are white and friable, of well-rounded grains, but show less of the fine lamination and cross-bedding than the St. Peter. Otherwise they seem to be of the St. Peter facies.

The formation is clearly marine throughout and carries the following fauna.

Fauna of the Jasper limestone.

Girvanella sp.
Scolithus sp.
Psiloconcha sp., short, subquadrate.
Psiloconcha sp., small and relatively short.
Whiteavesia ? sp.
Helicotoma sp. undet.
Raphistomina sp., apparently same as in Everton.
Plectoceras aff. P. jason (Billings).
Leperditia n. sp., valves large, compressed convex.
Leperditia (Isochilina?) n. sp., small, surface punctate.
Leperditella sp. undet.

This fauna is certainly not the familiar Plattin assemblage found in the upper Izard. For that reason, and also because of its abundant sand grains of St. Peter facies, as well as the presence of *Raphistomina*, which is highly characteristic of the Everton limestone, the Jasper is assigned to the St. Peter group and believed to occupy the well-known hiatus between the Joachim and Plattin.

Plattin.—This formation, the upper part of the Izard of older reports, while nowhere seen resting on the Jasper, is apparently younger than that formation, and rests on the Joachim (Lower Izard) with clear unconformity in Missouri. The relations do not seem to be clearly worked out in Arkansas.

In the older volumes of the Arkansas Survey[43] the Izard is described but no fossils are listed. It is there reported to lie between the "Calciferous" and the St. Clair limestone, which is said to be in part Trenton and partly higher.

A later report by H. S. Williams[44] states that no fossils were found in the Izard, but that it directly underlies the Polk Bayou limestone, in which abundant organic remains have been found, that show it to be characteristic Cincinnatian. The faunal list for the Polk Bayou will be given on another page (p. 46). The latest report on the region by Miser[45] while giving no fossil lists, assigns the name Plattin in Izard and Independence counties, to the upper part of the original Izard formation, and correlates it very specifically with the Plattin of Missouri. The formation is described as "even-bedded dove-colored or grayish-blue compact limestone." Miser indicates unconformity between the Plattin and Joachim, but gives none of the detailed evidence to prove the presence of such a break. Since it is well developed in Missouri, however, and since locally the Jasper appears to occupy at least a portion of the hiatus, it is probably present in Arkansas.

Kimmswick.—In the older reports the Izard is said to be followed by the St. Clair marble. This appears to have been a terrane, rather than a formation, and is said by Hopkins[46] to range in age from Trenton to Niagaran, this opinion being based on fossil identifications by H. S. Williams, though no faunal list is given in his report. The same opinion is expressed by Penrose[47]. The detailed identifications made by Williams[48] and published later, are given below. In his reports he divides up the old St. Clair terrane, and applies the name Polk Bayou to the Ordovician portion.

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[43] Hopkins, T. C., Marbles and other limestone; Ark. Geol. Survey, vol. IV, 1890-1891, pp. 121-124.

Penrose, R. A. F. Jr., Manganese, its uses, ores, and deposits; Ark. Geol. Survey, vol. 1, 1890-1893, pp. 108-115.

[44] Paleozoic faunas of northern Arkansas; Ark. Geol. Survey, vol. V, for 1892, 1900, pp. 277-280.

[45] Miser, H. D., Preliminary report on the deposits of manganese ore in the Batesville district, Arkansas; Bull. U. S. Geol. Survey, No. 715g, 1920.

[46] Hopkins, T. C., Ark. Geol. Survey, vol. IV, pp. 212-213.

[47] Penrose, R. A. F., Jr., Ark. Geol. Survey, vol. I. pp. 124-126.

[48] Williams, H. S., Ark. Geol. Survey, vol. V, pp. 277-280.
See also American Jour. Sci., vol. 48, 1894, pp. 325-331.

Fauna of the Polk Bayou limestone.

	Range.
Plectorthis plicatella Hall	T.-Mays.
Plectorthis fissicosta Hall (?)	Mays.
Dalmanella testudinaria (Dalman)	M.-U. Ord.
Platystrophia biforata (Schlotheim)	Ord.-Sil.
Plectambonites sericeus (Sowerby)	St. R.-Cin.
Rafinesquina alternata (Emmons)	T.-Rich.
Rafinesquina alternistriata Hall	Mays
Rafinesquina camerata (Conrad)	?
Rafinesquina deltoidea (Conrad)	T.
Strophomena nutans (Meek)	Rich.
Rhynchotrema capax (Conrad)	Rich.
Asaphus (Isotelus) gigas Dekay (?)	M. & U. Ord.
Ceraurus pleurexanthemus Green (?)	Bl. R.-T.
Monticulipora lycoperdon (Say)	?
Hebertella occidentalis Hall, var	Mays.-Rich.
Dinorthis pectinella (Emmons)	Bl. R.-T.

In these reports, Williams shows conclusively that the old St. Clair consists of at least two members, the lower, or Ordovician one of which he calls the Polk Bayou, and of this he says it "is more closely related to the Cincinnati group than to the Trenton of New York."

In the right hand column of the list is given an approximate analysis of the fauna. It is clearly dominated by Richmond forms. There are, however, one or two species that seem to be characteristic of Maysville, while *Rafinesquina deltoidea* is a typical Trenton form not known above the Utica. *Dinorthis pectinella* is also characteristic of Black River and Trenton rather than later beds. The *Ceraurus pleurexanthemus* is reported with a question mark, but if correctly placed, would also suggest the presence of beds not later than Trenton.

It is entirely probable that the Polk Bayou fauna of Arkansas, like that of the Receptaculite beds of Missouri, belongs to two independent horizons, Trenton and Richmond, with an intervening hiatus. This, according to Miser's[49] latest report, is actually the case. The lower part of the Polk Bayou is renamed Kimmswick, and said to be the equivalent of the Kimmswick of Missouri, whereas the upper part is called Fernvale, and correlated with that horizon to the north and east. Strangely enough, so far as the writer has been able to discover, there is nowhere any reference to the presence of *Receptaculites* in the lower Polk Bayou which Miser correlates with the Kimmswick of Missouri. This is particularly surprising, inasmuch as that horizon, in Missouri, is characterized by a great abundance of that form. Furthermore, the Kimmswick of Arkansas is described as "even bedded massive light-gray fine-grained limestone," whereas in Missouri it is more commonly described as white and coarsely crystalline. There is said to be unconformity between the Kimmswick and the underlying Plattin; but no evidence is cited to bear out the statement.

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[49] Miser, H. B., Bull. U. S. Geol. Survey No. 715g.

Fernvale.—As already described, the fauna of the Polk Bayou is typically Richmond, and the upper part of that formation is now correlated with the Fernvale of Tennessee. There is said to be unconformity at the base of the Fernvale. No evidence is presented in Miser's paper, for this statement, but since the unconformity is known in Missouri, and also farther west in Arkansas, the evidence seems to be sufficiently clear. In the Eureka Springs-Harrison Folio, the Fernvale is described as a coarsely crystalline light-gray limestone, which rests on the Jasper. The fact that it rests on the Jasper, with intervening formations, present in other localities, missing, is evidence of its unconformable relations. It has yielded the following fauna.

Fauna of the Fernvale in the Harrison quadrangle.

	Range.
Crepipora hemispherica Ulrich	Rich.
Anaphragma mirabile Ulrich and Bassler	Rich.
Phaenopora wilmingtonensis Ulrich	Rich.
Orthis cf O. laurentina Billings	Gamach.
Plectorthis whitfieldi (Winchell)	Rich.
Dalmanella porrecta Sardeson	Rich.
Dinorthis proavita Winchell and Schuchert	Rich.
Dinorthis subquadrata Hall	Rich.
Hebertella insculpta Conrad	Rich.
Strophomena cf S. cardinalis (Whitfield)	Rich.
Strophomena planodorsata Winchell and Schuchert	Rich.
Plectambonites praecosis Sardeson	Rich.
Parastrophia divergens Hall and Clarke	Rich.
Rhynchotrema capax (Conrad)	Rich.
Trochoceras ? (Gyroceras) baeri Meek and Worthen	Rich.
Isotelus n. sp. aff. I. jacobus Clarke	Tr.
Onchometopus cf O. susae (Calvin)	Rich.
Sphaerocoryphe maquoketensis Slocum	Rich.
Pterygometopus larrabee Slocum	Rich.

In the report on "Zinc and Lead Deposits of Northern Arkansas"[50], Ulrich also lists the following Fernvale fauna:

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[50] U. S. Geol. Survey, Prof. Paper 24, 1904, p. 98.

Fauna of the Fernvale in the Yellville quadrangle.

	Range.
Leioclema wilmingtonense Ulrich	Rich.
Monotrypella (Rhombotrypa) quadrata Rominger	Rich.
Dalmanella jugosa James (meeki)	Rich.
Dalmanella macrior Sardeson	Rich.
Platystrophia acutilirata Conrad	Rich.
Plectorthis kankakensis Mc Chesney	Rich.
Dinorthis proavita Winchell and Schuchert	Rich.
Rafinesquina kingi Whitfield	Rich.
Rhynchotrema capax Conrad	Rich.

Cason shale.—This formation, which lies next above the Fernvale, is described by Miser as a greenish-gray calcareous shale, sandy in places, and carrying manganese and phosphate rock. Its maximum thickness is 12½ feet. It is said to rest unconformably on the Fernvale, the evidence being the uneven contact and the irregular thickness of the Fernvale. It passes beneath the Silurian Brassfield limestone, and is assigned to the Richmond. The only fossils reported by Miser are specimens of *Girvanella* near *G. richmondensis.* This is probably the partial equivalent of the Maquoketa.

In the Eureka Springs-Harrison Folio, there is said to be a basal conglomerate at the base of the Cason. The following list of fossils is given in that report:

List of fossils from the Cason shale.

Calloporella sp.
Leptobolis occidentalis Hall.
Leptobolis sp.
Lingulops ? sp.
Lingula ? sp.
Schizotreta cf. S. pelopea (Billings).
Strophomena sp.
Dalmanella aff. D. testudinaria (Dalman).
Camarotoechia aff. C. neglecta (Hall).
Cyrtodonta ? sp.
Cyclora sp.
Coleolus iowensis ? James.
Orthoceras cf. O. sociale Hall.
Orthoceras sp.
Clymene mammillata Hall.
Pterygometopus ? sp.

The Ouachita Uplift in Arkansas.

Because of the complex structural relations of this region, and also because of the very different character of its formations from those exposed in the Ozark uplift, the stratigraphy of the Ouachitas has remained something of a puzzle. The latest report to be published[51] recognizes the following Ordovician formations:

O- 150 ft.	Polk Creek shale, black, graphitic, carries abundant graptolites.
700 ft.	Bigfork chert, carries graptolites.
1000 ft.	Womble shale, black, graphitic, numerous graptolites.
O- 400 ft.	Blakely sandstone, three fourths shale, a few graptolites.
1000 ft.	Mazarn shale, black and green shale, with graptolites.
850 ft.	Crystal Mountain sandstone, coarse gray, unfossiliferous.

The overlying Blaylock sandstone also carries graptolites, but is assigned by Ulrich to the Silurian system.

Miser's report, while referring to abundant graptolites at several horizons, unfortunately gives no faunal lists whatever. In Griswold's report on the "Whetstones and the Novaculites of Arkansas"[52], Dr. R. R. Gurley, an eminent authority on graptolites, has presented a discussion of the "Geological age of the Graptolite Shale of Arkansas." He recognizes two distinct horizons, Trenton, and Calciferous (Beekmantown). The Trenton he divides into two sub-horizons, that above the "Novaculites" and that just underneath. The most careful comparison of his locality notes with the Miser report just cited fails to reveal any positive clue by which the faunal lists of Dr. Gurley can be correlated with the revised section which Miser has presented. Since Miser's map does not differentiate the Ordovician formations, the careful location descriptions by Gurley do not avail.

Since, however, Miser gives the age of the true "Novaculites" as Devonian, and fails to mention any graptolites in association therewith, it is obvious that the reference of Dr. Gurley to graptolites above and below the "Novaculite" applies to some other formation., Purdue[53] mentions the fact that the Bigfork chert was mapped by Griswold as part of the Novaculite, and this gives a clue to the probable solution. This formation, together with the shales immediately above and below it quite certainly represent the horizon called Trenton by Dr. Gurley, which he describes as occurring both above and below the "Novaculite." This would include the Womble shale, the Bigfork chert, and the Polk Creek shale. He lists the following species from above the "Novaculite," probably from the Polk Creek shale.

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[51] Miser, H. D., Manganese deposits of the Caddo Gap and DeQueen quadrangles, Arkansas; Bull. U. S. Geol. Survey, No. 660, 1918, pp. 59-122.

[52] Ark. Geol. Survey, Ann. Rept. for 1890, 1892, pp. 401-424.

[53] Purdue, A. H., The slates of Arkansas; Geol. Survey of Ark. 1909, p. 36.

Trenton fossils above the "Novaculite."

	Range.
Diplograptus foliaceus Murch	Norm.
Glossograptus ciliatus Emmons	Norm.
Climacograptus antiquus Lapworth ?	Norm.
Dicellograptus sp	

The following species from below the "Novaculite," are probably from the Womble shale.

Trenton fossils below the "Novaculite."

	Range.
Coenograptus (Nemagraptus) gracilis Hall	Norm.
Diplograptus trifidus sp. n	Norm.
Diplograptus foliaceus Murch	Norm.
Diplograptus (Glossograptus) whitfieldi Hall	Norm.
Didymograptus sagittarius Hall (sagitticaulis)	Norm.
Didymograptus serratulus Hall	Norm.
Dicellograptus divaricatus Hall	Norm.
Dicellograptus elegans Carr. (divaricatus bicurvatus)	Norm.
Dicellograptus divaricatus rigidus Lapworth	String.
Dicranograptus ramosus Hall,	Norm.
Dicranograptus arkansasensis sp. n. (ramosus)	Norm.
Dicranograptus nicholsoni Hopk	Norm.
Dicranograptus angustifolius Hall	?
Climacograptus bicornis Hall	Norm.
Climacograptus antiquus Lapworth var. ?	Norm.
Cryptograptus tricornis Carr	Norm.
Glossograptus spinulosus Hall (ciliatus)	Norm.
Dictyonema obovatum sp. n	String.
Thamnograptus barrandii Hall (capillaris)	Norm.
Lasiograptus mucronatus Hall	Norm.
Leptograptus, like L. annectans Walc	Utica.

There can be no doubt whatever that this represents something close to the original Normanskill, which is now interpreted to be of Trenton age. According to Bassler[54] the Stringtown shale of Arkansas and Oklahoma is of Normanskill age. The Stringtown has recently been abandoned in Arkansas, as a formation name, that horizon being included in the upper part of the Womble shale, as that name is used by Miser in the report cited above. A number of the species in the list are also reported by Bassler to occur in the Stringtown.

From the "Calciferous" horizon Dr. Gurley also lists a considerable fauna. This, as nearly as can be judged by a comparison of the section, comes largely from the Mazarn shale, possibly in part from the Blakely sandstone.

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[54] Bassler, R. S., Bibiographic index of American Ordovician and Silurian fossils; U. S. Nat. Mus., Bull. 92, 1915, p. 1451.

Fossils from "Calciferous" of the Ouachita region.

	Deepkill forms.
Phyllograptus anna Hall	*
Phyllograptus typus Hall?	*
Schizograptus ? sp	
Dichograptus sp	*
Tetragraptus serra Brongn	*
Didymograptus sp. n?	*
Diplograptus dentatus Brongn	*
Cryptograptus antennarius Hall	*
Cryptograptus tricornis Carr	
Retiograptus tentaculatus Hall	*
Trigonograptus ensiformis Hall	*
Caryocaris wrightii Salter	Lower Ord.
Didymograptus caduceus Salter	*

Except for *Cryptograptus tricornis* this is a highly characteristic Deepkill fauna, and is undoubtedly Beekmantown. There can be little doubt, then, that the Mazarn shale is of Beekmantown age. Since it and the underlying Crystal Mountain sandstone are almost wholly clastic, as compared with the limestone of the Ozark region, it is clear that there was, in Beekmantown time, a land mass somewhere to the south from which this clastic material was derived.

The only dominantly sandy horizon above this Deepkill zone (Mazarn) is the Blakely sandstone. In this respect it suggests a correlation with the St. Peter, perhaps being a response to the same general disturbance that inaugurated the St. Peter epoch of coarser clastic sedimentation. That the St. Peter and Everton clastic material was, however, not derived from this direction, seems to be rather definitely indicated, by these facts: First, in the Ozark region, those formations grow increasingly calcareous, to the southeast and southwest. This they should not do in the direction of the land mass from which they were being derived. Second, the Blakely sandstone is much more argillaceous than the St. Peter. According to the recognized principles of sedimentation, the finer material should be transported farthest, so that the clays should not segregate nearest the land mass with purer sandstone farther out. Third, on the basis of paleogeographic probabilities it does not seem likely that these sands from a landmass to the south should be transported across a dominant trough, the Ouachita geosyncline, onto the broad continental shelf attached to the land mass of the Canadian shield on the north. The same criticisms apply to the sources of the Roubidoux. It seems therefore that while the Crystal Mountain sandstone and Mazarn shale were derived from a landmass to the south, the clastic material of the Roubidoux did not move across the geosyncline, but was derived from the north.

The dominantly limestone horizons of the Plattin and Kimmswick (Black River and Trenton) of the Ozark region are also represented in the Ouachitas by the Womble shale, the Bigfork chert, and the Polk Creek shale, largely clastic, and derived from the south.

OKLAHOMA.

The Ordovician of Oklahoma may be divided into three sub-provinces. These are the Ozark, the Arbuckle-Wichita, and Ouachita.

Ozark section.

The Fayetteville Folio, already cited under the discussion of Arkansas, gives a summary of the geologic conditions that applies also in part to the Ozark region of Oklahoma. More specifically applying to this region is the Tahlequah Folio (No. 122).

The oldest formation outcropping in this region is the Burgen sandstone, which is exposed along the crests of small folds near Tahlequah. Erosion has nowhere reached to the base of the formation, which is about 100 feet thick. It consists of a very pure silicious quartz sandstone, of well-rounded quartz grains, poorly cemented. No fossils are reported, but on lithologic grounds, it has been correlated with the St. Peter sandstone of Arkansas and Missouri. It is not known whether the equivalent of the Everton underlies the Burgen or not.

Above the Burgen rests the Tyner formation, from 60 to 100 feet thick. The lower half of the formation consists of green shale with thin interbedded brown sandstones. This horizon is non-fossiliferous. Above are about 20 feet of limestone, from which the following fossils are reported:

Fossils from upper limestone member of Tyner.

	Range.
Camarocladia rugosa Ulrich	Decorah.
Orthis tricenaria Conrad	St. R.-Bl. R.
Liospira americana Billings	St. R.-Rich.
Lophospira sp., of the type of perangulata	Chazy-Bl. R.
Hormotoma gracilis var	Tr.-Rich.
Leperditia, near L. fabulites Conrad	St. R.-Bl. R.
Leperditia n. sp	
Ceraurus pleurexanthemus Green	Bl. R.-Tr.

The list suggests Black River and points to equivalency with the Plattin of Arkansas and Missouri. The lower non-fossiliferous part might then be a somewhat shaly equivalent of the Joachim. The shale, which here seems to replace lime as we pass southwest, suggests the increasing influence, as the beds are traced southward, of the land mass south of the Ouachita geosyncline, just as the gradation of the Joachim northward into sandstone, suggests the approach to the northern sources for the typical St. Peter. There does not seem, in this section, to be any equivalent of the Kimmswick. However, a thin sandstone and shale above the fossiliferous limestone yielded the following fauna:

Fauna from upper shale beds of the Tyner.

Psilochoncha inornata Ulrich.
Psilochoncha sinuata Ulrich.
Psilochoncha cf. subovalis Ulrich.
Rhytimya sp. undet.
Whiteavesia sp. undet.

The first three forms are typically Maysville, while the last two genera also range through that horizon. While the fauna is too small to warrant any positive conclusion, it suggests an incursion of the Maysville sea into this region; though the Missouri and Arkansas sections studied show Richmond (Fernvale) next above the Trenton. This may perhaps represent a northern embayment of the Ouachita geosyncline. Our knowledge of the Ouachita region is too fragmentary to be able to say either that it was or was not connected with the well-known Maysville embayment, though this fauna quite probably entered the region by this route, between the island of Ozarkia and the larger continent south of the Ouachita geosyncline. Above the Tyner rest Silurian and Devonian beds. No Richmond is reported. This is all the more striking, since the characteristic Fernvale fauna is well developed farther south and west in the Arbuckle region.

The Ouachita section of Oklahoma.

A description of the rocks of this region is to be found in the Atoka Folio (No. 79). In the northeast corner of this quadrangle occur rocks belonging to the Ouachita ranges, apparently continuous with those of the Ouachita of Arkansas, while about 15 miles farther west in the same quadrangle, occurs the typical Arbuckle section, in which rocks of the same age expose notably different facies. In the Ouachita region, the oldest bed described is the Stringtown shale of unknown thickness, a black to green fissle shale, reported to carry Ordovician graptolites, though no faunal list is given. Bassler[55], however, lists numerous typical Normanskill graptolites from the Stringtown, and Miser[56] correlates it with the upper part of the Womble shale of Arkansas. This has already been shown to be of Trenton age. Above this in the Atoka region rests the Talihina chert said to be 1200 feet thick, and from which no fossils are reported. It seems, from its position above the Stringtown and from its lithologic character, to be the equivalent of the Bigfork chert of Arkansas, which also is of probable Trenton age.

Above this, with reported gradational contact, rests the Standley (Stanley) shale and the Jackfork sandstone. Later studies[57], however, show that there is unconformity at this contact, and that the Standley (Stanley) and Jackfork are of Carboniferous age, not Ordovician as stated in the Atoka Folio. Accordingly no higher Ordovician beds are reported in this section than Trenton.

The anomaly of the Ouachita section with its thick series of clastics ranging from Stringtown (Trenton) to Jackfork (Carboniferous), only fifteen miles from the Arbuckle section, where beds of equivalent age are almost wholly limestone, has been one of the big puzzles in Oklahoma stratigraphy. Wallis[58] says:

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[55] Bassler, R. S., Bibliographic index.

[56] Miser, H. D., Bull. U. S. Geol. Survey, No. 660, pp. 59-122.

[57] Girty, G. H., The fauna of the Caney shale of Oklohoma; Bull, U. S. Geol. Survey, No. 377, 1909, p. 6.
Miser, H. D., loc. cit.
Honess, C. W., The Stanley shale of Oklahoma; Am. Jour. Sci., vol. 1, 5th ser., Jan. 1921, pp. 63-80.

> **"While the Viola limestone was being deposited in the Arbuckle Mountain region, sedimendation of a markedly different character was taking place less than 20 miles distant in the Ouachita Mountain region."**

That lateral gradation in the character of sediments actually is of common occurrence, the writer does not doubt. That a thin series might even wholly change in lithologic aspect within a few miles, is entirely possible. When, however, such a change is abrupt throughout several thousand feet of sediments, the problem becomes vastly more difficult. It is almost inconceivable that the two totally different sections, the Ouachita almost wholly clastic, the Arbuckle almost wholly limestone, and both measured in thousands of feet, could have been produced simultaneously by normal processes of sedimentation within 15 miles of each other.

To the writer, the observed conditions suggest an enormous overthrust fault, the displacement measured in scores of miles, which may have crowded the Ouachita facies from the south or southeast far to the northwest, over the Arbuckle facies, probably in pre-Caney times. In such a case, the relations to the old land mass to the south would be essentially those of the southern Appalachians, where the force seems to have acted from the direction of the land mass, driving blocks out over the geosynclinal area to the northwest. Such an interpretation would satisfactorily solve the paleogeographic problem involved, and is apparently worth considering in any further structural studies of the Ouachita-Arbuckle uplift.

The Arbuckle-Wichita section of Oklahoma.

The essential features of this stratigraphic succession are summed up in the Atoka and Tishomingo Folios (Nos. 79 and 98) and in Professional Paper 31.

Arbuckle.—The lowest Ordovician beds are the Arbuckle limestone, the base of which is Cambrian and the top clearly Beekmantown. Owing to the fact that fossil collections have apparently not been made throughout all horizons of this formation, the exact position of the Cambrian-Ordovician boundary is not known. It is variously estimated that from 1200 to 3000 feet of the upper portion is Ordovician. It is slightly sandy and shaly near the top. From these upper beds, the following fauna is reported:

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[58] **Wallis, B. F., The geology and economic value of the Wapanucka limestone of Oklahoma; Oklahoma Geol. Survey, Bull. No. 23, 1915, p. 25.**

Fauna of the upper Arbuckle limestone.

Billingsella, 2 species.
Polytoechia ?
Stromatocerium.
Colathium, 2 species.
Maclurea.
Ophileta.
Eccyliomphalus.
Eccyliopterus.
Raphistomina.
Leiospira (? Helicotoma).
Euconia (near E. ramsayi Billings).
Hormotoma, 2 species, one very near H. artemesia Billings.
Trochonema.
Orthoceras.
Trochoceras.
Leperditia.
Isochilina.
Primitia.
Bathyurus.
Isotelus canalis?

This list, while generic only, is a representative Beekmantown assemblage.

Simpson.—Resting above the Arbuckle with reported slight unconformity, is the Simpson formation. Since considerable interest attaches to the interpretation of the Simpson, the following detailed section by Taff[59] is appended.

Detailed section of Simpson formation, Oklahoma.

		Feet.
1.	Thin limestone with green shales interstratified	400
2.	Sandstone	90
3.	Limestone and shales interbedded	400
	Orthis tricenaria, O. deflecta, and *Ctenodonta sp.*	
4.	Sandstone	100-200
5.	Shaly limestone, lower 50 feet fossiliferous	195
	Ostracods, crinoid stems and bryozoa.	
6.	Sandstone	33
7.	Thin-bedded limestone and shales interstratified	295
	Fossils abundant; Ostracods, gastropods, pelecypods, brachiopods, and trilobites.	
8.	Greenish shales with a few thin limestones	245
	Thin sandstone.	
9.	Granular limestone	350
	Ostracods abundant, other fossils very rare.	
10.	Thin limestones, shales, and occasional sandstones	29
11.	White to light brown sandstone, local	0-100

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[59] Prof. Paper 31.

It is reported that the Simpson thins northward by the suppression of the lower beds, and also that the upper members become notably more sandy, toward the north. These facts have a distinct bearing on the paleogeography, and point to the derivation of the silicious material from the north, as was shown to be the case with certain formations in the Ozark region.

Fossils lists are given, both from the lower and from the upper parts of the formation. An attempt has been made, in the last column to analyze and evaluate the lists, by comparing, with the ranges given in Bassler's "Index."

Fossils of the lower Simpson.

	Range.
Siphonotreta sp. undet	**Beek.-Tr.**
Crania sp. nov	**St. P.-Niag.**
Orthis costata	**Mays.**
Orthis (Dalmanella) pogonipensis Walcott (Pianodema)	**Bl. R.-Tr.**
Orthis sp. ? nov. (near O holstoni Safford)	**Chazy.**
Ctenodonta sp. nov. (of C. nasuta type)	**Bl. R.-Tr.**
Ctenodonta sp. nov. (large, ovate species)	**St. P.-Sil.**
Cyrtodonta sp. undet	**St. P.-Rich.**
Modiolopsis sp. nov	**St. P.-Medina.**
Modiolopsis sp. nov	**St. P.-Medina.**
Bucania sp. undet (small, with flat dorsum)	**St. R.-Brass.**
Bucanella sp. undet	**L. Ord.-Sil.**
Maclurea sp. undet	**Beek.-Tr.**
Eccyliopterus sp. undet	**Beek.-Tr.**
Leperditia sp. near fabulites	**St. R.-Bl. R.**
Leperditella, several species undet	**St. R.-Rich.**
Leperditia bivia White	**Bl. R.-Tr.**
Bathyurus sp. undet	**Beek.-Tr.**
Ceraurus, 2 species undet	
Amphion nevadensis ? Walcott	

Since specific identifications are almost wholly lacking the list is not very conclusive. Three of the genera do not normally range below Black River, one is listed as Maysville, and as for the rest, they might equally well be anything from Chazy to Trenton. The presence of well-developed Black River and Trenton faunas over a thousand feet higher suggests Chazy as the strongest possibility. It is not stated through how great a thickness of the lower beds this fauna extends, nor precisely the association of forms.

The upper 300 feet of the Simpson has also yielded an important fauna, which is listed below, with an analysis and evaluation in the last column.

Fauna of the upper Simpson.

	Range.
Receptaculites sp. nov	Chazy-Niag.
Protaraea sp. nov	Tr.-Niag.
Archaeocrinus sp. undet	Chazy-Niag.
Platycystites (?) sp. nov	Chazy.
Amygdalocystites sp. nov	Tr.
Glyptocystites sp. nov.	Tr.
Stomatopora proutana-pertenuis Ulrich	St. R.-Rich.
Phylloporina (Chasmatopora) sublaxa Ulrich	St. R.-Bl. R.
Rhinidictya nicholsoni Ulrich	Low.
Arthroclema sp. nov	Bl. B.-Rich.
Pachydictya cf. foliata Ulrich	Bl. R.
Lingula coburgensis Billings	Tr.
Schizambon (?Siphonotreta) minnesotensis H. & C	Bl. R.
Crania granulosa Winchell	Bl. R.
Craniella (Petrocrania) ulrichi Hall	Bl. R.-Tr.
Pholidops trentonensis Hall	Tr.
Plectambonites sericeus (Stones River var.)	St. R.
Strophomena filitexta (incurvata) Hall	St. R.-Bl. R.
Rafinesquina minnesotensis Winchell	Bl. R.
Scenidium anthonense Sardeson	Bl. R.
Orthis tricenaria Conrad	St. R.-Bl. R.
Dalmanella perverta Conrad (Pianodema subaequata)	St. R.-Bl. R.
Dinorthis near pectinella Emmons	Bl. R.-Tr.
Orthis (?Dinorthis) deflecta Conrad	St. R.-Bl. R.
Orthis (?Dinorthis) sp. nov	
Hebertella bellarugosa Conrad	Chazy-Bl. R.
Triplecia sp. nov. (striated)	
Zygospira (Hallina) nicolleti W. & S	Bl. R.
Zygospira (Hallina) sp. nov	
Clionychia lamellosa Hall	Bl. R.
Ctenodonta contracta Salter	Bl. R.
Eurymya plana Hall	Bl. R.
Tetranota obsoleta ? Ulrich	Bl. R.-Eden.
Pterotheca attenuata Hall	Low.-Bl. R.
Amphyx sp. undet	
Harpina sp. undet (Eoharpes)	
Platymetopus sp. nov. near P. bicornis Ulrich	Rich.
Platymetopus sp. nov. near P. cucullus M. & W	Bl. R.-Tr.
Pterygometopus near schmidti Clarke	Bl. R.-Tr.

This fauna is considered by Ulrich to be close to that of the upper Stones River of Tennessee and Kentucky. The analysis presented above shows a dominance, among the specifically identified forms, of Black River species, particularly of the Platteville and Decorah beds. The large number of new species cannot be evaluated, and might conceivably point to a slightly earlier assemblage, of which the Platteville and Decorah were the later modified migrants.

Furthermore, it is not exactly clear what is included in the upper Stones River, particularly as reference is made to equivalent beds in the upper part of the Mississippi Valley. Since the Platteville there rests next above the St. Peter, one might logically interpret the statement to include Platteville in the Stones River group. The writer inclines to the view that the upper 300 feet of the Simpson includes beds as late as Lowville and early Black River and closely equivalent to the Platteville.

If this includes the Lowville equivalent, it furnishes some basis for a comparison of the age of the lower horizons with those farther to the north. On the assumption that the top of the Simpson is near Lowville, there are about 1000 to 1500 feet of limestones with some interbedded sandstones and shales, below Lowville and above the most pronounced break in the series, that between the upper Arbuckle (Beekmantown) and the base of the Simpson.

This unconformity is probably the St. Peter break, so widespread and important in central United States. In Wisconsin, there is between Lowville ? (basal Platteville) and this unconformity only the St. Peter sandstone. In Missouri, there occurs below Lowville ? (basal Plattin) the Joachim limestone, which is probably the offshore limestone equivalent of part of the St. Peter farther north, followed in turn by the St. Peter below, and the Everton at the base, which is in part certainly equivalent to the St. Peter farther north, but is quite probably in part actually lower. In Arkansas, below the Lowville ? (basal Plattin) occurs the Jasper limestone and Joachim, in descending order, both with sandstone lenses of the St. Peter facies, then below this the St. Peter itself, and the Everton, the total thickness of these beds (which may be spoken of as the St. Peter group) reaching a maximum of over 400 feet.

Apparently, from here southwest, the unconformable surface diverges still more rapidly, until in the Arbuckles there intervene 1500 feet of beds, largely limestone, between the Lowville (?) horizon and the old erosion surface. Just how much of this thickening may be due to more rapid accumulation, and may therefore represent the same time interval as the thinner beds in Arkansas and Missouri, it is not possible to say. Since, however, both series are largely limestone, and since the source of the sands seems to have been in a general northerly direction, it does not seem that accumulation should have been much, if any, more rapid to the south. The limestones, then, probably thicken by the coming in of older series to the south; and this is the normal interpretation, with a sea encroaching from the Ouachita geosyncline and gradually spreading northward.

The basal sandstones of the Simpson, then, are probably actually older than the Everton, and may bear much the same relation to the Everton that the latter bears to the St. Peter. Under this interpretation, the Simpson, like the Everton, may be spoken of as belonging to the St. Peter group, but it would be out of place to actually enlarge the formational name St. Peter to include any part of the Simpson.

It is probably not possible to correlate exactly any particular sandstone of the Simpson with either the St. Peter or the Everton, though these formations are likely closer to the middle than the base of the Simpson.

Unfortunately, the descriptions of the physical character of the Simpson leave much to be desired, so that any comparison of it with the St. Peter on these grounds is not safe. The most thorough descriptions that the writer has been able to find are presented by Buttram[60], who describes several detailed sections in those regions that are believed to have possibilities of glass sand development. His measured sections show several rather massive sandstone members, but in general the sandstones are intimately interbedded with shale and limestone layers, and resemble the Everton sections described in Arkansas and Missouri, except that more shale occurs in the Simpson formation. A study of the various sections seems to indicate that the beds are not persistent, but that they grade laterally from one type of sediment into another. The many interbedded limestones, even in the more dominantly sandy portions, show clearly the marine conditions under which the Simpson was laid down. The sandstone layers average well above 90 percent silica, while many show a purity of 98 and 99 percent, being in this respect comparable to the St. Peter. They are described as characterized by freedom from clay, by uniformity of size, and by sub-rounded grains.

Viola.—Above the Simpson and in apparent conformity with it is the Viola limestone, 500 to 700 feet thick. Sandstone and clay layers occur, but are rare. The formation is divisible into three members. The lower one, not over 100 feet thick, consists of a rather coarsely-crystalline limestone. It has yielded the following fauna:

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[60] Buttram, Frank, The glass sands of Oklahoma; Bull. Okla. Geol. Survey, No. 10, 1913, pp. 43-76.

Fossils of the lower 100 feet of the Viola.

	Range.
Streptelasma profundum var	Bl. R.
Tetradium columnare Hall	Tr.
Homotrypa intercalaris Ulrich	Bl. R.
Bythopora subgracilis Ulrich	Bl. R.
Phylloporina (Chasmatopora) reticulata Hall	Bl. R.-Tr.
Rhinidictya mutabilis major Ulrich	Bl. R.
Rhinidictya mutabilis Ulrich	Bl. R.-Tr.
Escharopora subrecta Ulrich	Bl. R.
Phaenopora incipiens Ulrich	Tr.
Arthropora bifurcata Ulrich	Bl. R.-Tr.
Plectambonites sericeus var	Bl. R.-Rich.
Strophomena filitexta (incurvata) Hall	St. R.-Bl. R.
Rafinesquina deltoidea Conrad	Tr.
Dalmanella hamburgensis ? Walcott	Bl. R.
Dinorthis pectinella Hall	Bl. R.-Tr.
Platystrophia sp. undet	Ord.-Sil.
Rhynchotrema increbescens Hall	Tr.
Żygospira recurvirostris Hall	Bl. R.-Tr.
Vanuxemia gibbosa Ulrich	Tr.
Technophorus subacutus ? Ulrich	Bl. R.
Cyrtolites retrorsus Ulrich	Bl. R.
Protowarthia (Sinuites) pervoluta U. & S	Bl. R.-Tr.
Lophospira bicincta Hall	St. R.-Rich.
Strophostylus textilis U. & S.	Bl. R.-Tr.
Holopea obliqua ? Hall	St. P. ? Tr.
Pterotheca attenuata Hall	Bl. R.
Bumastus trentonensis Emmons	Tr. (?).

This fauna has a dominantly Black River aspect, but carries forms also characteristically Trenton. As correlated by Ulrich, it is said to be late Black River and early Trenton. The middle Viola member is white to light blue well-bedded limestone, about 300 feet thick, and has also yielded a small fauna.

Fauna of the middle Viola.

	Range.
Diplograptus pristis? Hall	Norm.
Climacograptus typicalis Hall	Tr.-Eden.
Schizotreta minutula W. & S	Rich.
Conotreta, sp. undet. (? rusti Walcott)	Tr.
Rafinesquina deltoidea Conrad	Tr.
Conularia trentonensis Hall	Tr.
Trinucleus concentricus Eaton	Tr.-Mays.
Trinucleus sp. undet	?
Proetus parviusculus var	Mays.
Pterygometopus (near callicephalus Hall)	Tr.
Nileus vigilans M. & W	Bl. R.-Rich.

This fauna, while dominated by Trenton forma, includes several species that are abundant higher in the section, and suggests later Trenton, as proposed by Ulrich. The upper member, about 300 feet thick, consists of light gray crystalline limestone. A small fauna is listed from the upper 50 feet of this member.

Fauna from upper 50 feet of Viola limestone.

	Range.
Pachydictya gigantea Ulrich	**Rich.**
Ptilotrypa obliquata Ulrich	**Rich.**
Plectambonites sp. nov.	**?**
Strophomena wisconsinensis Whitfield	**Rich.**
Leptaena unicostata M. & W.	**Rich.**
Rafinesquina sp. nov. (near camerata)	
Orthis (Plectorthis) kankakensis sweeneyi Winchell	**Rich.**
Dinorthis subquadrata Hall	**Rich.**
Dinorthis proavita W. & S.	**Rich.**
Hebertella insculpta Hall	**Rich.**
Dalmanella macrior Sardeson	**Rich.**
Platystrophia acutilirata Conrad	**Rich.**
Rhynchotrema capax Conrad	**Rich.**
Parastrophia divergens H. & C.	**Rich.**

This is a characteristic Richmond fauna, apparently the equivalent of the Fernvale already described from Arkansas and Missouri. How great a thickness of this upper member belongs to the Richmond is not clear, though probably not an amount greatly in excess of the fifty feet of more fossiliferous beds, near the top. It is quite possible that the less fossiliferous limestone immediately below may include earlier Cincinnatian beds. The presence of a Maysville fauna near Tahlequah (p. 53) suggests this possibility. It is not even possible to estimate how great a thickness might be so accounted for. Probably not over an additional 100 feet, if any.

Since the top of the Simpson has been herein interpreted as probably including the Lowville horizon, this would leave at the lowest estimate, about 400 feet or more of the lower and middle Viola between the Lowville and the Cincinnatian, which is 50 percent greater than the thickness reported in Missouri, Arkansas and Wisconsin. Differences of this magnitude, even where both formations are limestone, might easily be ascribed to equal time intervals, on the basis of different rate of accumulation. On the other hand, if Ulrich is right in interpreting unconformity between the Plattin and Kimmswick in Missouri and Arkansas, it is possible that the Viola actually includes beds representing that gap, beds not present farther north.

IOWA.

Oneota.

The oldest formation in Iowa to be referred to the Ordovician is the Oneota dolomite. In the older reports this formation is described as including all the beds between the St. Croix sandstone below and the St. Peter above.[61] The St. Peter, however, appears to have sometimes been used in an expanded sense, to include the New Richmond sandstone and Shakopee dolomite, and when so used, involved the present conception of the term Oneota, as the lowest member of the Prairie du Chien as that term is now used. On the other hand, Oneota, as formerly used, sometimes included also New Richmond[62] and Shakopee, and the older descriptions must be used with this caution in mind. The present terminology recognizes the three divisions of the Prairie du Chien mentioned above. the Oneota at the base, then New Richmond and Shakopee in ascending order.

The Oneota is best described in certain county reports of the Iowa Geological Survey[63], from which the following descriptions are largely abstracted. One must discriminate carefully, however, between the varying usages of the term. The Oneota, as delimited at present, averages not far from 150 feet in thickness, and consists of a gray, rather crystalline limestone, for the most part massive and poorly bedded, outcropping in cavernous crags and pinnacles. It is exposed only over a very small area in the northeastern part of the state, but occurs more deeply buried in all but the northwest corner, where it was removed by pre-Cretaceous erosion.

Several of the reports cited above describe faunas from the Oneota, but a careful study of the context shows, in every case, that these are Shakopee faunas from the upper half of the Oneota of the older writers, and not from the lower, or true Oneota. The exact stratigraphic position can therefore not be directly determined. The fact, however, that below the St. Peter break, we have in descending order the Shakopee, New Richmond, and Oneota, the first and last being dominantly limestone, the New Richmond essentially a sandstone, at one suggests correlation with the Gasconade, which is similarly situated below the Roubidoux sandstone in Missouri. This view is strengthened by the similarity of the Oneota and Gasconade.

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[61] Keyes, C. R., Geological formations of Iowa; Iowa Geol. Survey, vol. 1, Ann. Rept. for 1892, pp. 11-144.

[62] Leonard, A. G., Geology of Clayton County; Iowa Geol. Survey, vol. XVI, Ann. Rept. 1905, p. 239.

[63] Calvin, Samuel, Geology of Winneshiek County; Iowa Geol. Survey, vol. XVI 1905, pp. 64-65.
Leonard, A. G., Geology of Clayton County, same volume, pp. 239-243.
Calvin, Samuel, Geology of Allamakee County; Iowa Geol. Survey, vol. 4, 1894, pp. 61-68.

This involves some difficulty of interpretation, however, since in Missouri, the Roubidoux has recently been considered to be the base of the Ordovician, whereas, in most of the reports on Iowa, the Oneota is included in the Ordovician series. Bassler[64], following Ulrich's latest revision, places the base of the Canadian (lowest Ordovician) at the top of the Gasconade and Oneota, which he considers to be equivalent beds.

New Richmond.

This formation has been differentiated in Iowa only in the newer reports. The older geologists mapped it either as part of the St. Peter, or as part of the Oneota, sometimes one and sometimes the other interpretation being followed. The best descriptions of it are given by Calvin[65], and Howell[66].

The formation, which rarely exceeds 30 feet in thickness along the outcrop, consists essentially of sandstone, with thin layers of interstratified dolomite. In some localities, the dolomite appears to be dominant, with several sandy layers. Descriptions suggest rapid lateral variation. It is much more thinly and regularly bedded than the St. Peter. Ripple marks are abundant throughout, and the sand grains show exceptional development of quartz enlargement (Pl. XX, B). Fossils have not been reported from the New Richmond. In position and lithologic characteristics, it clearly resembles the Roubidoux of the Ozarks, with which it is here correlated.

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[64] Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils; Bull. U. S. Nat. Mus., No. 92, 1915, plate 2.

[65] Calvin, Samuel, Geology of Winneshiek County; Iowa Geol. Survey, vol. XVI, 1905, pp. 68-71.

[66] Howell, J. V., The iron ore deposits near Waukon, Iowa; Iowa Geol. Survey, vol. XXV, 1914, p. 43.

According to Norton[67], the New Richmond, which he refers to as the "intervening sandstone" of the Oneota, thickens to the southwest, as indicated by well records, to at least 130 feet. This statement must be accepted with caution, since several sandy layers are known in Missouri in the overlying Jefferson City and Cotter horizons. Nevertheless, since the Roubidoux averages perhaps 100 feet thick in Missouri and the New Richmond is about 30 feet thick at its outcrop in northeastern Iowa, it is probable that it does actually thicken somewhat to the south.

Shakopee.

This formation was formerly included either in the upper Oneota, or the basal St. Peter, but is now restricted to the dolomite resting above the New Richmond and below the St. Peter. It is the upper member of the Prairie du Chien series. It is best described in the county reports already mentioned (p. 63).

The Shakopee rarely exceeds 100 feet in thickness, in outcrop, but 240 feet has been described in well records. It outcrops only in the northeast corner of the state, but is almost everywhere present beneath younger beds, except in the extreme northwest counties, where Cretaceous overlaps directly onto older beds. In general it is a dolomite, less massive, better bedded, less crystalline, and with a less tendency to form cliffs, than the Oneota. In these respects the two formations show differences comparable to those between the Gasconade and Jefferson City, in Missouri. It is characterized by the abundance of concretion-like masses of *Cryptozoon minnesotense*, in which respect it also closely resembles the Jefferson City and Cotter formations of Missouri.

Calvin[68] gives a list of fossils from the upper Oneota. He states that:

> "All the specimens in the collection came from thin bands and irregular masses of chert that are more or less common throughout the upper half of the Oneota. With the exception of a single imperfect specimen of *Straparollus claytonensis* none of the species mentioned above are at present known from the masses of limestone making up the main part of the Oneota, or from the intercalated sandstones and shales in the upper part of the formation."

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[67] Norton, W. H., Thickness of the Paleozoic strata of northeastern Iowa; Iowa Geol. Survey, vol. III, 1893.

[68] Calvin, Samuel, Iowa Geol. Survey, vol. XVI, pp. 66-67; also Amer. Geologist, vol. 10, 1892, pp. 144-148. Also Bull. Lab. Nat. Hist., State Univ. Iowa, vol. 2, 1891-93, pp. 189-193.

As near as it is possible to determine from the above description, in which Oneota is used in the larger sense, these remains must represent the Shakopee horizon.

Fossils from the Shakopee.

	Range.
Tryblidium sp. undet	
Murchisonia sp. undet	
Metoptoma (Scenella?) alta Whf	**Beek.**
Straparollus claytonensis Calvin	**Oz.**
Straparollus pristiniformis Calvin	**Oz.**
Raphistoma pepinense Meek	**Oz.**
Raphistoma multivolvatum Calvin	**Oz.**
Raphistoma paucivolvatum Calvin	**Oz.**
Holopea (Sinuopea) turgida Hall	**Oz.**
Orthoceras primigenium Vanuxem	**Beek.**
Cyrtoceras luthei Calvin	**Oz.**

Howell[69] also lists the same fauna, quoting Calvin. In Howell's report, the three members of the Prairie du Chien are distinguished, and the Oneota is restricted to its present usage. Nevertheless he says "Calvin has described the following forms from the chert beds of the Upper Oneota of Allamakee county," giving the impression that the fossils came from the Oneota restricted. Calvin's statement, quoted above, is so specific, however, that the only interpretation seems to be that the list is Shakopee, and that Howell merely failed to call attention to the fact that Calvin was using the term in its older sense, to include the whole of the Prairie du Chien.

The forms were all checked in Bassler's "Index," where it was found that they are ascribed to Oneota, and not to Shakopee. An analysis of the fauna, however, yields the following facts: the genera *Tryblidium* and *Murchisonia* have no diagnostic value, without specific identifications. *Metoptoma* (*Scenella?*) *alta* and *Orthoceras primigenium* are characteristic of the Beekmantown elsewhere. The remainder of the forms are ascribed to the Ozarkian. Of these, however, the only one to be found outside the region is *Holopea* (*Sinuopea*) *turgida*, which is Ozarkian elsewhere. The rest of the forms, since they are found only in this section, are of no significance. This leaves two species definitely Beekmantown, against one supposed to be older, and the remainder without bearing one the case. These facts, then, offer no obstacle to considering that the fauna is from the top of the Oneota, used in the old sense, or from the Shakopee, in our newer nomenclature. And this interpretation is certainly strongly suggested in the quotation given from Calvin (p. 65).

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[69] Howell, J. V., Iowa Geol. Survey, vol. XXV, p. 44.

While the faunal evidence here presented is entirely inadequate for establishing any exact correlation, the lithology and succession place the Shakopee as equal to either the Jefferson City, or Cotter, or both, farther south. This is borne out by faunal evidence from other localities (pp. 39-40, 98, 111).

St. Peter.

This formation rests on the eroded surface of the older beds. This condition is manifested chiefly by the very irregular and sudden variations in level of its lower contact. This was formerly attributed to folds in the older beds[70], but later studies have clearly set forth the evidence of unconformity at this particular horizon. In fact, it has been shown that the failure to find the equivalent of the New Richmond in many sections is owing to the fact that the pre-St. Peter eroison has, in places, cut deeply enough to entirely remove the Shakopee and New Richmond, allowing the St. Peter to rest directly on the Oneota. This situation undoubtedly had much to do with the various interpretations of the Shakopee and New Richmond as part of the Oneota and as part of the St. Peter. It is quite certain, then, that the unconformity actually exists, in spite of the repeated statements of older writers that the St. Peter rests conformably and with gradational contact upon the older beds. It is quite likely, however, that the statements of gradation rest in part on the misconception that the New Richmond was part of the St. Peter series. The evidences for unconformity have been convincingly summed up by Trowbridge[71] and are generally of the same sort as the writer was able to discover in his own field work, done in Missouri, before Trowbridge had reported his results from Iowa. Of these, the most striking is the pre-St. Peter relief of at least 200 feet. Equivalent to this evidence is the frequently repeated statement that the St. Peter varies rapidly and irregularly in thickness from place to place. The other most striking evidence is the chert conglomerate in the basal St. Peter, derived from the older cherty horizons.

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[70] Norton, W. H., Iowa Geol. Survey, vol. III, 1893, pp. 181-182.

[71] Trowbridge, A. C., The Prairie du Chien-St. Peter unconformity in Iowa; Iowa Acad. Sci., vol. XXIV, 1917, pp. 177-182.

Directly in line with this is the peculiar condition reported from the log of a well at Maquoketa, where, beneath the St. Peter, occurs 241 feet of brick-red argillaceous sandstone, the grains of which are rounded, and bedded in red shale. It is interpreted by Norton[72] as possibly a continental deposit, at the base of the St. Peter. The evidence, now abundantly presented, of unconformity at the base of the St. Peter, strengthens the possibility of Norton's interpretation. This solution is also directly in line with the presence of red residual soils discovered by the writer, at the base of the St. Peter series in Missouri (p. 15). Similar conditions are also reported from Minnesota and Illinois (pp. 85, 98).

In thickness, the St. Peter in Iowa is reported to range from 15 feet, in Marion county[73] to 223 feet at Pictured Rocks[74]. The sand, here, as elsewhere, consists of the usually pure silicious aggregation of well-rounded quartz grains. One would gather, from the descriptions, that it is somewhat more ferruginous in Iowa than in Missouri, though even in Iowa, all reports agree that a considerable portion of the iron-staining is superficially infiltrated.

Bedding is developed in places, though in general the formation is rather massive. Cross-bedding is also reported, but the descriptions do not imply any very unusual degree of cross-bedded structure. In fact Hall[75] distinctly calls attention to the lack of development of cross-stratification, and Norton[76] states that "no traces of lamination or oblique stratification appear." This statement, while of course too sweeping, is a fair illustration of the over-emphasis that cross-bedding has received, in usual conceptions of the St. Peter.

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[72] Norton, W. H., Underground water resources of Iowa; U. S. Geol. Survey, Water, Supply Paper, No. 293, 1912, pp. 69-70.

[73] Norton, W. H., Underground water resources of Iowa; U. S. Geol. Survey, Water Supply Paper No. 293, 1912, p. 800.

[74] Trowbridge, A. C., The Prairie du Chien-St. Peter unconformity in Iowa; Iowa Acad. of Sci., vol. XXIV, 1917, p. 180.

[75] Hall, James, Report on the geological survey of the State of Iowa, vol. I, 1858, p. 337,

[76] Norton, W. H., Underground water resources of Iowa; U. S. Geol. Survey, Water Supply Paper No. 293, 1912, p. 71.

Occasional shale layers are described. Reported limestone layers near the base quite probably belong to the Shakopee horizon.[77] On the other hand, in places limestone beds are reported well up in the formation. These, so far as can be learned, have not been described from the outcrop but are reported by Norton[78] from numerous well records. A well at Postville, in Allemakee county, shows 13½ feet of sandstone of the usual type of rounded St. Peter grains, then 52 feet of shaly limestone with many fossil fragments, and below that 13 feet of calcareous sandstone. Since this county is one of those in which the St. Peter is exposed extensively, the failure of such a limestone bed to outcrop is very peculiar to say the least. It is reported, however, that the cuttings were all carefully saved, and studied in detail, so there can be little doubt of the presence of this limestone mass in the sandstone. Calvin[79] has interpreted it as a cavern in the St. Peter, filled with inwashed shale and limestone from above. This explanation is perfectly possible. It was advanced at a time, however, when limestone layers were not known in the St. Peter series. In working in Missouri, the writer has actually traced the Everton limestone from beds 55 feet thick to beds 5 feet thick in a distance of not over ten miles. In the case cited above, the nearest outcrops of the St. Peter are said to be 8 miles distant from the well. It is not impossible for a limestone lens to have thinned out to practical disappearance in that distance. The discovery of the Everton in Missouri lends a new interest to this occurrence, and should stimulate a more careful search of the outcrop, for possible limestone beds, in the more northern states.

A well in Floyd county passes entirely through the St. Peter, which is 80 feet thick. The upper 10 feet consists of clean quartz sand grains, well-rounded. Below this is 40 feet of sandstone and dolomite, the quartz grains well-rounded, with considerable white chert, gray dolomite, and green shale. At the base is 30 feet of clean white sandstone. In Cerro Gordo, the next county west of Floyd, a well at Mason City cuts 77 feet of St. Peter. Near the center of the formation is reported a layer, the thickness of which is not over 10 feet, consisting of sandstone, limestone and shale. In a well in Bremer county, adjacent to Floyd on the east, the drill passed through 66 feet of St. Peter. Sixteen feet below the top of the formation, limestone chippings are reported in the drillings. The limestone might have fallen in from above, but in view of the unquestioned presence of limestone layers in the formation in adjacent counties, the record is at least suggestive. In another paper, Norton mentions the presence of limestone beds in the St. Peter at Dubuque.[80]

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[77] Keyes, C. R., Iowa Geol. Survey, vol. I, 1892, pp. 24-25. Also vol. II, 1894, p. 105.

[78] Norton, W. H., Water Supply Paper 293, pp. 251, 271, 412, 605, 631, 639, 677, 751.

[79] Calvin, Samuel, Apparent anomalies of stratification in the Postville well; Amer. Geol., vol. 17, 1896, pp. 195-203.

In Jackson county, the St. Peter is 106 feet thick, and a four foot shale bed is described, 25 feet below the top. In Des Moines county the St. Peter is 120 feet thick. The upper layers consist of clear white sand, and 55 feet below the top, is 40 feet of sandstone like the above, but containing much hard green shale. At the base are 25 feet of white clean sandstone. In Boone county, green shales are also reported in the formation.

In Wapello county, the drill passes through material which Norton has hesitated to correlate. The doubtful part of the section, from top down, is as follows:

Sandy limestone	75-125	feet.
Water bearing sandstone	75-100	feet.
Limestone	100	feet.
Green shale	20	feet.
White sandstone	40	feet.

The cuttings were not seen by Norton, but various records agree closely enough to indicate that these formations were really encountered. Norton reports that one or the other of these sandstones must be the St. Peter. His failure to consider the possibility of both belonging to the St. Peter series is probably to be ascribed to the fact that at the time his work was done, little or nothing was known of the presence of the Everton in the more southern states. Numerous records have already been presented to show the presence of limestone in the St. Peter, even in Iowa, and the writer is inclined to the view that this represents an embayment of the Everton sea, extending northward into Iowa. One of the most serious difficulties in the way of this is the failure to recognize such a horizon in closely adjacent areas. This may be, in part, due to the failure to study the cuttings with sufficient care. It must also be remembered that the Everton has an extremely irregular development, where it is best known. Owing to the unconformable surface on which it rests, it is very thin or absent in places. Also, as already described (pp. 15-18), the limestone members thicken and thin with surprising irregularity. It hardly seems to admit of doubt, however, that there is in Iowa, near the middle of the St. Peter a shaly and limey horizon. This will have some bearing on any interpretation of the history of the region.

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[80] Norton, W. H., Artesian wells of Iowa; Iowa Geol. Survey, vol. VI, 1896, p. 144.

The St. Peter outcrops only in the northeast corner of Iowa but its importance as an aquifer has led to an extensive study of it in drill records. Over the greater part of the state, it is present below younger formations, but is not found in the northwesternmost counties, where Cretaceous beds rest directly in the Sioux quartzite, of pre-Cambrian age. Bain has suggested[81] that this region constituted a land mass against which the Paleozoic beds were deposited with progressive overlap, portions of the land not being submerged until as late as Cretaceous time. The writer is somewhat more inclined to believe that the Cambrian and possibly the Beekmantown beds may have overlapped this land mass far beyond the Iowa border, and that the outer fringes of these were removed during the interval of the St. Peter break, yielding already assorted Cambrian sand to the St. Peter. This is suggested by the fact that there appears to be no particular change in thickness or character of the St. Peter, when traced in this direction, as there might be if an old crystalline land mass existed in such close proximity. It seems even probable that the St. Peter itself was laid down in this corner of the state, and has since been removed in a pre-Cretaceous interval. This interpretation seems to be borne out by the fact that in Palo Alta, Cherokee, and Ida counties, which are the points farthest northwest where the St. Peter has been penetrated, it appears to be of perfectly normal thickness and purity, and shows no evidence of the proximity of a mixed crystalline source.

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[81] Bain, H. F., Geology of Woodbury County; Iowa Geol. Survey, vol. 5, 1895, pp. 256-259.

A well in Woodbury county penetrates the pre-Cambrian at 1260 feet, having passed through about 700 feet of Paleozoic in which the St. Peter cannot be recognized. The writer is inclined to believe that the St. Peter was removed before the Cretaceous was laid down, and that the first horizon to be encountered below the Cretaceous is either the Shakopee or New Richmond. This is suggested by the fact that in Plymouth, the next county to the north, the Cretaceous seems to be resting directly on pre-Cambrian, and that similar overlap occurs in Minnesota (p. 101).

No fossils have been found in the St. Peter, in Iowa, so that its correlation depends upon the proper correlation of the overlying and underlying beds.

Platteville.

Next above the St. Peter, with thin intervening bluish shale layers, rests the Platteville formation. There is no visible evidence of an unconformity between the two. It has already been shown (p. 26) that evidence of erosion of the incoherent underlying sand of the St. Peter would be easily obliterated, so that it is not possible to say whether any appreciable time elapsed before the deposition of the Platteville.

The formation is essentially a limestone, though the shaly layers between it and the St. Peter are usually included, and also sometimes the overlying Decorah shale. The limestone proper averages about 50 feet in thickness. The lower beds are buff colored and relatively unfossiliferous. The middle layers are light gray and bluish, and very rich in fossils. The upper part of the formation is thinner-bedded and more shaly.

Howell[82] lists the following forms from the Platteville not including Decorah. They were identified by Professor A. O. Thomas.

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[82] Howell, J. V., Iron ore deposits near Waukon; Iowa Geol. Survey, vol. XXV, 1914, pp. 48-50.

Fossils from the Platteville limestone.

		Range.
Streptelasma corniculum	G.	T.
*Orthis (Pianodema) subaequata	P.	St. R.-Bl. R.
*Orthis tricenaria	P.	St. R.-Bl. R.
Orthis (Dalmanella) testudinaria	G.	Bl. R.-Rich.
Rafinesquina alternata	P.-G.	T.-Rich.
Strophomena (Rafinesquina) minnesotensis	P.	Bl. R.
Strophomena sp		
Strophomena rugosa (planumbona)		Rich.
Leptaena rhomboidalis		Tr.-Waverly.
Leptaena unicostata		Rich.
Rhynchotrema dentata		T.-Rich.
Plectambonites sericeus	P.-G.	Bl. R.-Rich.
Ambonychia (Byssonychia) radiata		Mays-Rich.
Avicula sp		
*Liospira vitruvia	P.	Bl. R.-Rich.
Trochonema umbilicatum	P.-G.	Bl. R.-T.
Trochonema sp		
*Murchisonia (Hormotoma) gracilis	P,-G.	Tr.-Rich.
Bellerophon, 3 sp		
Hyolites sp		
Orthoceras sp		
Oncoceras pandion	P.	Bl. R.
Ceraurus pleurexanthemus	P.-G.	Bl. R.-Tr.
Isotelus iowensis (?)		Rich.
Isotelus gigas	G.	Bl. R.-Rich.
Calymene sp		
Bumastus sp		
Ascidaspis sp		
Beyrichia sp		

This list has been analyzed according to the ranges given in Bassler's "Index." The first column indicates by *P.* or *G.* whether the forms are listed from known Platteville or Galena. In the second column is given the known range of each species. It will be noted that eight or nine of the species are not listed from the Platteville, and do not range lower than the Trenton. Four of them do not range below Cincinnatian. This may be accounted for in any one of three ways. In the first place it is possible that different faunas from separate horizons were actually mixed in the collecting in the field. Again, it may be possible that not all the identifications are exact. And it is possible that these lists may extend the known range of a few of the forms.

The position of the Platteville below known Trenton (Galena) makes it certain that forms limited to the Cincinnatian could not be present. Eliminating these doubtful cases, the list has a dominantly Black River aspect. By its faunas it correlates with considerable assurance with the Plattin of Missouri and Arkansas, and it is known to be continuous with the Platteville of the adjacent states to the north and east. The four species marked with a star are known from beds elsewhere correlated with the Lowville, but are not especially characteristic of that horizon.

Calvin[83] calls attention to the abundance of *Endoceras proteiforme* Hall. This is elsewhere reported from both Platteville and Galena, and is therefore not discriminative.

Leonard[84] lists numerous species, which he says "were collected in strata lying from 10 to 15 feet below the Galena dolomite and about 120 feet below Maquoketa." It must be borne in mind, however, that his list was published before the Platteville ("Trenton") was delimited in the manner now defined, as that limestone lying between the St. Peter below and a persistent shale horizon, the Decorah, above. In the older reports, the "Trenton" was defined as the lower non-dolomitic and the Galena as the upper dolomitic portion of the limestone lying between the St. Peter below and Maquoketa above. And since, as a number of writers have shown,[85] there is no constant horizon, down to which the dolomitization occurs, the "Trenton" of the older writers included the non-dolomitic beds below the present Decorah, the Decorah itself, and not uncommonly a considerable part of the overlying Galena as now delimited. This makes it difficult to evaluate the faunas listed.

Leonard's list of "Trenton" fossils.

		Range.
Rafinesquina minnesotensis Winchell	P.	Bl. R.
Rafinesquina alternata Conrad	P.-G.	T.-Rich.
Hormotoma trentonensis Ulrich	G.	T.
Liospira vitruvia Billings	P.	Bl. R.-Rich.
Platystrophia biforata		Ord.-Sil.
Isotelus gigas DeKay	G.	Bl. R.-Rich.
Fusispira elongata Hall	G.	T.
Illaenus americanus Billings	G	T.

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[83] Calvin, Samuel, Geology of Winneshiek County; Iowa Geol. Survey, vol. XVI, 1905, p. 84.

[84] Leonard, A. G., Geology of Clayton County; Iowa Geol. Survey, vol. XVI, 1905, pp. 254-255.

[85] Calvin, Samuel, Iowa Geol. Survey, vol. X, 1899, pp. 402-423. Leonard, A. G., Iowa Geol. Survey, vol. XVI, 1905, pp. 247-259. Norton, W. H., Iowa Geol. Survey, vol. VI, 1896, p. 146.

		Range.
Trochonema umbilicatum Hall	P.-G.	Bl. R.-T.
Clionychia lamellosa Hall	P.	Bl. R.
Fusispira angusta Ulrich	G.	T.
Fusispira inflata M. and W.	G.	T.
Oncoceras pandion Hall	P.	Bl. R.
Ischadites iowensis Owen	G.	T.
Cyrtodonta grandis Ulrich (?)	G.	T.
Parastrophia schofieldi Ulrich	G.	T.
Anastrophia (Parastrophia) hemiplicata Hall	P.-G.	T.
Lophospira bicincta Hall	P.-G.	St. R.-Rich.
Eccyliopterus sp		
Liospira lenticularis Sowerby		
Hormotoma salteri Ulrich	G.	T.
Lingula iowensis Owen	G.	T.
Orthis (Dalmanella) testudinaria Dalman	G.	Bl. R.-Rich.

This list is so strongly of Trenton aspect, and contains so large a proportion of forms elsewhere listed from the Galena, that it is certain they belong to the Galena, as now defined, and not to the Platteville. Only three forms reported exclusively from the Platteville are present, while a large proportion are reported exclusively from the Galena or its equivalents. This and the preceding list seem certainly to represent two different horizons.

Calvin[86] lists a number of species from undifferentiated Galena-Trenton from Howard county. A careful study of his descriptions seems to indicate, however, that all his specimens came from the Galena. He also lists several species from the "Trenton" of Allamakee county[87]. It appears, however, from the descriptions, that most, if not all, of these forms are from the Decorah, at that time included in the "Trenton."

Calvin and Bain[88] list "Trenton" fossils from Dubuque county. A study of their sections shows two important fossil-bearing horizons. The higher of these, a shale, is almost certainly the Decorah. Below that they list the following:

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[86] Calvin, Samuel, Geology of Howard County; Iowa Geol. Survey, vol. XIII, 1902, pp. 40-70.

[87] Calvin, Samuel, and Bain, H. F., Geology of Allamakee County; Iowa Geol. Survey, vol. IV, 1894, pp. 76-80.

[88] Calvin, Samuel, and Bain, H. F., Geology of Dubuque County; Iowa Geol. Survey, vol. X, 1899, pp. 412-423.

"Trenton" fossils.

		Range.
Rafinesquina alternata Conrad	P.-G.	T.-Rich.
Strophomena planumbona Hall		Rich.
Plectambonites sericeus Sowerby	P.-G.	Bl. R.-Rich.
Orthis (Plectorthis) plicatella Hall	G.	Tr.-Mays.
Orthis (Planodema) subaequata Conrad	P.	St. R.-Bl. R.
Trochonema umbilicatum Hall	P.-G.	Bl. R.-T.

An analysis of this list is not very enlightening. One species, *Strophomena planumbona*, is a typical Richmond form. Another, *Plectorthis plicatella*, is not known below the Galena. One is reported elsewhere from the Platteville and not the Galena, the remaining three are reported from both Platteville and Galena. Owing to its position with respect to the "Green Shale" (Decorah) the horizon is probably Platteville.

Decorah.

This formation, in the older reports, was either classed with the Platteville, or with the Galena, more often with the former. It is occasionally referred to as the "Green Shale." It varies from 10 to 40 feet in thickness, thinning rapidly southward. Ulrich[89] recognizes the Decorah fauna as far south as the Ozarks. The rocks carrying this fauna to the south appear to be much more calcareous than farther north. The thickening of the shale faces northward, and its gradation into limestone southward indicates, as does much evidence already cited, the sources of sediment to the north, for this great interior region, in early and middle Ordovician time.

Howell[90] lists an important fauna from the Decorah.

Fossils reported from the Decorah.

	Decorah.	Galena.	Range.
Ceraurus pleurexanthemus	x	x	Bl. R.-Tr.
Liospira vitruvia	x		Bl. R.-Rich.
Streptelasma corniculum		x	Tr.
Monticulipora (Hallopora) pulchella			
Rhinidictya sp			
Prasopora simulatrix	x	x	Bl. R.-Tr.
Lingula iowensis		x	Tr.
Orthis tricenaria	x		St. R.-Bl. R.
Platystrophia acutilirata			Rich.

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[89] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, 1911. p. 367.

[90] Howell, J. V., Iron ore deposits near Waukon; Iowa Geol. Survey, vol. XXV, 1914, pp. 49-50.

	Decorah.	Galena.	Range.
Dalmanella (Pianodema) subaequata	x		St. R.-Bl. R.
Dalmanella testudinaria	x	x	Bl. R.-Rich.
Dinorthis pectinella	x		Bl. R.-T.
Dinorthis subquadrata			Rich.
Hebertella bellarugosa	x		Chazy-Bl. R.
Hebertella insculpta			Rich.
Rhynchotrema capax			Rich.
Rhynchotrema inequivalvis (increbescens)		x	Tr.
Rhynchotrema perlamellosa			Rich.
Rhynchotrema anticostiensis			Rich.
Plectambonites sericeus	x	x	Bl. R.-Rich.
Strophomena filitexta (incurvata)	x		St. R.-Bl. R.
Strophomena nutans			Rich.
Strophomena planumbona			Rich.
Rafinesquina alternata		x	Tr.-Rich.
Rafinesquina minnesotensis	x		Bl. R.
Leptaena rhomboidalis			Tr.-Waverly
Fusispira nobilis		x	Tr.
Fusispira intermedia		x	Tr.

This assemblage, upon anlysis, shows 11 forms listed from the Decorah elsewhere, 6 forms noted from the Galena but not from the Decorah, and 8 forms highly characteristic of the Richmond (Maquoketa). The list, excluding the Richmond species, has a dominantly Black River aspect, and is most closely related to the Plattin of Missouri, of which it is believed to be a northern more clastic facies. The presence of the Richmond forms can be ascribed to some one of several possibilities. One of these is improper identification. This seems to be excluded, owing to the considerable number of Richmond forms highly characteristic, that have little likelihood of being confused with any known Black River forms. Another explanation might be a recurrent fauna, but this, too, seems to be excluded, since these forms, if recurrent, should be more widely reported from the Decorah. It might be possible that the material was collected from talus slopes, in which there was an actual mixing of forms from various horizons. The account gives no clue to this interpretation. Since there is a hiatus below the Maquoketa involving all the Eden and Maysville, it is also possible that in this locality, the Richmond may rest on or very closely above the Decorah, so that fossils collected in situ might come from both horizons, without the collector recognizing the fact.

Calvin[91] gives a list of fossils from the "Green Shale" horizon of the "Trenton." This is doubtless Decorah. The characteristic species are said to be *Orthis tricenaria* Con., *Orthis* (*Pianodema*) *subaequata* Con., and *Ceraurus pleurexanthemus* Green. *Strophomena planumbona* Hall is also reported. In another report Calvin[92] described a small fauna from a shale horizon, immediately beneath the Galena and 100 feet beneath the Maquoketa horizon.

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[91] Calvin, Samuel, and Bain, H. F., Geology of Dubuque County; Iowa Geol. Survey, vol. X, 1899, p. 419.

Fauna from "Trenton" (?) shale.

	Range.
Rafinesquina minnesotensis Winchell	Bl. R.
Plectorthis kankakensis McChesney	Rich.
Orthis (Dinorthis) subquadrata Hall	Rich.

The first form is characteristic of the Platteville, of which the Decorah is essentially a phase. The two last are characteristic Richmond forms, and the same suggestions might apply, as were made for Howell's list (p. 77). From another shale horizon, described in the same report, are listed these forms:

Fauna from "Trenton" (?) shale.

	Range.
Prasopora simulatrix Ulrich	Bl. R.-Tr.
Orthis (Pianodema) subaequata Con	St. R.-Bl. R.
Orthis (Hebertella) bellarugosa Con,	Chazy-Bl. R.
Platystrophia biforata cf. acutilirata	St. R.-Rich.
Strophomena rugosa Rafinesque	Rich.
Strophomena incurvata Shepard	St. R.-Bl. R.
Rhynchotrema ainsliei Winchell	Bl. R.
Rhynchotrema inequivalvis (increbescens)	Tr.

This is a characteristic Black River assemblage, except for *Strophomena rugosa*, which may quite possibly be a misidentification, and *Rhynchotrema increbescens*, which occurs in the immediately overlying Galena. In another report, Calvin[93] has recognized the Decorah as a separate formation, and lists the following fauna:

Fauna from the Decorah shale in Winneshiek County.

	Range.
Streptelasma corniculum Hall	Tr.
Prasopora simulatrix Ulrich	St. R.-Bl. R.
Strophomena incurvata Shepard	St. R.-Bl. R.
Plectanbonites sericeus Sowerby	St. R.-Rich.
Orthis tricenaria Conrad	St. R.-Bl. R.
Orthis (Dalmanella) testudinaria Dalman	Bl. R.-Rich.
Orthis (Pianodema) subaequata Conrad	St. R.-Bl. R.
Orthis (Plectorthis) plicatella Hall	Tr.

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[92] Calvin, Samuel, Geology of Allamekee County; Iowa Geol. Survey, vol. IV, 1894, p. 76-79.

[93] Calvin, Samuel, Geology of Winneshiek County; Iowa Geol. Survey, vol. XVI, 1905, pp. 85-87.

This list is also strongly Black River in its general aspect, though a few Trenton forms are present. The Decorah of Iowa is correlated with that formation in Minnesota. It is less prominent, but still recognizable in Wisconsin. Its assemblage of forms is recognizable as a distinct fauna, according to Ulrich as far south as Missouri.

Galena.

In the older reports, this term was applied to the upper dolomitized portion of the complex of shale, limestone, and dolomite lying between the St. Peter below and the Maquoketa above. Since the dolomitization is irregular in downward extent, the formation was not sharply delimited. Later usage has, therefore, restricted the term to that chiefly dolomite horizon extending from the Decorah shale below to the Maquoketa horizon above. As thus restricted, it averages not far from 250 feet in thickness, and consists essentially of rather massive crystalline buff dolomite. It is reported to grade into the Decorah below, through thin-bedded transition layers. The upper and lower Receptaculites zones lie respectively 70 feet below the top, and 40 feet above the base of the formation, and are persistent horizons. The Gastropod zone lies 10 feet below the upper Receptaculites horizon. It carries *Maclurea bigsbyi*, *Hormotoma major*, *Trochomena umbilicatum*, *Maclurina cuneata*, *Murchisonia bellicincta*, *Fusispira elongata*, and *F. inflata*. These horizons, according to the descriptions, seem to be persistent enough so that it should be easily possible, by reference to them, to determine whether or not the top of the Galena has undergone unequal erosion, in pre-Maquoketa time.

Howell[94] reports the following fossils from the Galena:

Galena fauna.

	Range.
Maclurea (Maclurites) bigsbyi	**Bl. R.**
Hormotoma major	**T.**
Trochonema umbilicatum	**Bl. R.-T.**
Maclurina cuneata	**T.**
Murchisonia (Hormotoma) bellicincta	**T.**
Fusispira elongata	**T.**
Fusispira inflata	**T.**

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[94] **Howell, J. V., Iron ore deposits near Waukon; Iowa Geol. Survey, vol. XXV, 1914, pp. 51-53.**

	Range.
Receptaculites oweni	**Bl. R.-T.**
Ischadites iowensis	**T.**
Plectambonites sericeus	**Bl. R.-Rich.**
Rafinesquina alternata	**T.-Rich.**
Streptelasma corniculum	**T.**
Dalmanella testudinaria	**Bl. R.-Rich.**
Platystrophia lynx	**Bl. R.-Rich.**
Lingula iowensis	**T.**
Hormotoma gracilis	**T. Rich.**

This is a characteristic Trenton assemblage. A similar list containing no additional species is given in the report on Winneshiek county[95]. The list already analyzed (p. 74) is also from the Galena, and is characteristically Trenton. In the geology of Dubuque county[96] are also reported several of the above species, and two additional forms, *Orthis* (*Hebertella*) *bellarugosa*, and *Orthis* (*Plectorthis*) *plicatella*. The former is common in the Black River, the latter in the Trenton. Savage[97] reports many of the same forms and in addition the following:

Additional Galena fossils.

	Range.
Fusispira ventricosa (inflata) Meek	**Tr.**
Fusispira nobilis U. and S	**Tr.**
Trochonema robbinsi U. and S	**Tr.**
Zittelella lobata U. and E	**Bl. R.**
Lophospira fillmorensis ? U. and S	**Tr.**
Rafinesquina deltoidea Conrad	**Tr.**
Rafinesquina minnesotensis Winchell	**Bl. R.**
Strophomena incurvata Shepard	**St. R.-Bl. R.**
Hormotoma subangulata	**Bl. R.**
Orthis (Platystrophia) biforata	**St. R.-Rich.**
Rhynchotrema capax	**Rich.**

The presence of four Black River forms in this group known to be common in the Platteville, but not elsewhere listed from the Galena, is probably merely a result of the old indefinite idea of the boundary between the two, which has resulted in the collecting of a mixed fauna. Otherwise, either the identifications are faulty, or the range of these three forms must be slightly extended. There is no evidence to decide between these possibilities.

On the basis of the contained faunas, the Galena correlates with the same formations in Minnesota, Wisconsin, and Illinois, into which, indeed, it has actually been traced with perfect continuity. Its faunal relations are intimate with the Kimmswick of the Ozark region. Ulrich[98], however, believes the Kimmswick to be older than the Galena, and reports that the latter is actually seen to rest on the former, in Pike and Lincoln counties, Missouri. The Kimmswick, he says, is late Black River. The fact that the one rests on the other would not necessarily prove them as a whole, to be of different ages, inasmuch as they might represent overlapping wedge-shaped facies of a single continuous formation. The most striking common feature of the two is the extreme abundance of Receptaculites. While the writer is not in possession of any actual data to disprove Ulrich's view, he does feel that, as yet, Ulrich has not presented any convincing data to bear out his conclusion, which, if true, is of great importance in stratigraphic interpretation. In the absence of such facts, it seems like a much simpler and more logical interpretation to assume the contemporaneity of these formations, in so far as isolated areas of formations can ever be proved to be contemporaneous.

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[95] **Calvin, Samuel, and Bain, H. F., Iowa Geol. Survey, vol. XVI, 1905, pp. 87-94.**

[96] **Calvin, Samuel, and Bain, H. F., Iowa Geol. Survey, vol. X, 1899, pp. 420-431.**

[97] **Savage, T. E., Iowa Geol. Survey, vol. XV, 1904, pp. 461-463, also vol. XVI, 1905, pp. 592-597.**

Maquoketa.

The Maquoketa is the highest of the Ordovician formations described in Iowa, and consists of a gray and bluish-gray calcareous shale, with a maximum reported thickness of about 300 feet. The thickness, however, is extremely variable, probably in part because of the hiatus not only at the base but at the top of the formation as well. Occasional thin beds of limestone are intercallated, a few of which reach, locally, considerable thickness. The formation is highly organic and pyritiferous and rich in fossils. It varies in character abruptly from place to place.

Calvin[99] lists a fauna from this horizon.

Fauna of Maquoketa shale.

	Range.
Leptobolis occidentalis Hall	Rich.
Isotelus maximus Locke	Tr.-Rich.
Asaphus (Isotelus) iowensis Owen	Rich.
Lingula rinciformis Hall	Tr.

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[98] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. Amer., vol. 22, 1911, pp. 309, 369-371, 466, 479, 524.

[99] Calvin, Samuel, Geology of Winneshiek County; Iowa Geol. Survey, vol. XVI, 1905, pp. 94-109.

	Range.
Diplograptus peosta (?) Hall	Rich.
Conularia trentonensis Hall	Tr.
Plectambonites sericeus Sowerby	Bl. R.-Rich.
Orthis (Dalmanella) testudinaria Dalman	Bl. R.-Rich.
Orthis (Platystrophia) biforata	Ord. Sil.
Rafinesquina alternata Conrad	Tr.-Rich.
Rhynchotrema capax	Rich.
Strophomena planumbona	Rich.
Orthis (Plectorthis) whitfieldi	Rich.
Orthis (Dinorthis) subquadrata	Rich.
Hormotoma gracilis	Tr.-Rich.
Isotelus gigas	Bl. R.-Rich.
Orthis (Hebertella) insculpta	Rich.
Nileus vigilans (?)	Bl. R.-Rich.
Orthis (Plectorthis) plicatella	Tr.-Mays.
Orthoceras cf. sociale	Rich.
Lingula iowensis Owen	Tr.
Rhynchotrema perlamellosa	Rich.
Glyptocrinus sp	

Leonard[100] also lists a considerable fauna from the Maquoketa. Most of the forms he gives are included in the list already published. Additional species are:

	Range.
Rhynchonella (Rhynchotrema) neenah	Rich.
Calymene senaria (C. meeki)	Rich.
Leptaena unicostata	Rich.
Tentaculites (Cornulites) sterlingensis	Rich.

Savage,[101] in addition to those already listed, many of which he reports, also notes the presence of the following additional species:

Savage's list of Maquoketa fossils.

	Range.
Leptaena rhomboidalis	Tr.-Waverly
Calymene cf. mammilata Hall	Rich.
Orthis (Hebertella) occidentalis	Mays.-Rich.
Rhynchonella (?) (Rhynchotrema) anticostiensis	Rich.
Strophomena cf. nutans	Rich.
Byssonychia radiata	Mays.-Rich.
Streptelasma corniculum Hall (probably rusticum)	Tr.-Rich.
Zygospira modesta	Eden-Rich.
Cyrtolites ornatus (?)	Mays.-Rich.
Strophomena planumbona Hall	Rich.
Strophomena incurvata Shepard	St. R.-Bl. R.
Orthis (Dinorthis) proavita	Rich.
Pterinea demissa	Mays.-Rich.
Hindia parva Ulrich	Bl. R.-Tr.
Rafinesquina alternata var. loxorhytis Meek	Rich.

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[100] Leonard, A. G., Geology of Clayton County; Iowa Geol. Survey, vol. XVI, 1905, pp. 266-275.

[101] Savage, T. E., Iowa Geol. Survey, vol. XVI, 1905, pp. 597-609; also vol. XV, 1904, pp. 463-488.

	Range.
Rafinesquina minnesotensis Winchell	Bl. R.
Strophomena fluctuosa Billings	Rich.
Strophomena trilobata Owen	Tr.
Clitambonites diversa? Shaler	Tr.-Rich.
Orthis (Plectorthis) plicatella Hall	Mays.
Orthis (Dinorthis) pectinella (Emmons) Hall	Bl. R.-Tr.
Orthis (Dalmanella) hamburgensis Winchell	Bl. R.
Platystrophia biforata var. acutilirata James	Rich.
Rhynchotrema inaequivalvis (increbescens)	Tr.
Zygospira recurvirostris Hall	Bl. R.
Lophospira quadrisulcata U. and S	Rich.
Bellerophon bilobatus Sowerby (?) (Sinuites cancellatus)	Tr.-Rich.
Trochonema umbilicatum Hall	Bl. R.-Tr.
Gyronema pulchellum ? U. and S	Bl. R.
Cyclonema bilix Conrad	Rich.
Ambonychia (Byssonychia) intermedia M. & W	Tr.
Orthoceras (Spyroceras) bilineatum Hall	Bl. R.-Tr.
Cameroceras (Endoceras) proteiforme Hall	Tr.
Cyrtoceras camurum ? Hall	Bl. R.-Tr.
Trochoceras ? (Gyroceras) baeri M. & W	Rich.
Bumastus orbicaudatus Billings	Rich.
Ceraurus (Ceraurinus) icarus Billings	Rich.
Ceraurus pleurexanthemus Green	Bl. R.-Tr.
Pterygometopus callicephalus Hall	Tr.

These faunas are dominantly Richmond, though 21 of the total of 65 species are not listed by Bassler from that horizon. Thirteen of these 21 species occur only near the base of the Maquoketa. These may either represent a slight extension in the known range of the forms, or may result from a mixing of faunas. Since Eden faunas are not represented at all, and Maysville by only two species, it seems quite certain that these series are represented in the section by a pronounced hiatus, and this makes less probable than otherwise might be, any extension of Trenton forms into Richmond, in this region, that does not occur also in the type region where the section is so much more complete.

All descriptions suggest great diversity in character of the lowest Richmond, and while no positive proof has been secured, there appears to be reason to suspect a somewhat irregular erosion surface, which would allow for changes from Galena to Richmond along the strike, and might easily account for a mixing of the faunas of the lower beds in collecting. There might even be the incorporation of some Trenton forms in the base of the Richmond.

ILLINOIS.

Prairie du Chien.

The oldest formation in Illlnois to be referred to the Ordovician is the Prairie du Chien. This formation has a very limited outcrop in the state, being exposed in several isolated patches along the crest of the anticline from LaSalle northwest in LaSalle, Lee, and Ogle counties, and farther south in Calhoun county. The formation includes beds equivalent, from the base upward, to the Oneota, New Richmond and Shakopee of Iowa, Wisconsin and Minnesota. So far as descriptions could be found, the oldest rock to outcrop is the Shakopee, the lower members being known only from drill records. Cady[102] gives the most complete description of the Prairie du Chien in Illinois. The Oneota portion of the Prairie du Chien, as shown by drill records, is about 200 to 225 feet thick. Above it are found alternating sandstones and dolomites correlated on the basis of stratigraphic character with the New Richmond of Iowa. Cady gives the following section of this complex compiled from well records.

Section of the New Richmond, near LaSalle, from well records.

Sandstone, colorless quartz grains	37 feet.
Sandstone and dolomite	9 feet.
Sandstone, colorless quartz grains	16 feet.
Sandstone and dolomite	14 feet.
Sandstone, coarse, colorless	46 feet.
Sandstone and dolomite	8 feet.
Dolomite and sandstone	3 feet.
Sandstone, fine; little limestone	3 feet.
Total	136 feet.

The figures are average. The known variation is reported to be from 80 to 188 feet. Its position, character, and average thickness justify its correlation with the New Richmond of Iowa and Wisconsin, and with the Roubidoux of Missouri.

The Shakopee, which outcrops sparingly, varies from 170 to 232 feet in thickness, and consists chiefly of dolomite, with occasional thin sandstone lenses. Cherty masses resembling Cryptozoons and a few gastropods, too poorly preserved to be identified, are the only fossils reported. The Shakopee is correlated with the Shakopee of Iowa, Wisconsin, and Minnesota on the basis of its stratigraphic position and lithologic character. It is also the equivalent of the Jefferson City, and probably of at least part of the Cotter, of Missouri and Arkansas.

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[102] Cady, G. H., Geology and mineral resources of the Hennepin and LaSalle quadrangles; Ill. Geol. Survey, Bull. No. 37, 1919, pp. 33-36.

St. Peter.

This formation rests on the eroded surface of the Shakopee, the evidence of unconformity, according to Cady, consisting of a contact with irregular pre-St. Peter relief of over 50 feet, together with a basal conglomerate made up of weathered fragments of chert, from the underlying cherty limestones. Anderson[103] quotes Ulrich to the effect that in wells near Chicago, the basal St. Peter probably rests in places on the Oneota, with the Shakopee completely cut out. According to Anderson,[104] the contact between the two is frequently marked by a red shale and cherty horizon. Numerous well records reported by Stone[105] show a red marl at the base of the St. Peter. A well at Joliet[106] also shows 40 feet of similar red marl, while Udden[107] reports the same sort of material from wells near Rock Island. This is interpreted as the equivalent of the red residual soil described by the writer, which occurs in Missouri (p. 15) at the base of the St. Peter; and it also resembles material reported from the Maquoketa well of Iowa (p. 68), and from certain areas in Minnesota (p. 98).

Cady[108] cites some reason for believing that the Prairie du Chien (Lower Magnesian) was slightly deformed, before the St. Peter was laid down, but the evidence is not at all conclusive.

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[103] Anderson, C. B., The artesian waters of northeastern Illinois; Ill. Geol. Survey Bull. No. 34, 1919, p. 109.

[104] Anderson, C. B., Artesian waters, p. 84.

[105] Stone, Leander, The artesian wells of Chicago; Bull. Chicago Acad. Sci., No. 1, 1883-86, pp. 93-102.

[106] Leverett, Frank, The water resources of Illinois; Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 799.

[107] Udden, J. A., An account of the Paleozoic rocks explored by deep borings at Rock Island, Illinois, and vicinity; Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 838.

[108] Cady, G. H., The structure of the LaSalle anticline; Ill. Geol. Survey, Bull. No. 36, 1920, p. 109.

The formation is reported[109] to vary between 89 and 420 feet in thickness, but Weller[110] in a more recent report places the maximum at 275 feet. Blatchley[111] shows local variations ranging between 115 feet and 297 feet in short distances, and Anderson[112] reports that variations of 100 feet in short distances are not unusual, and gives an extreme range of from 20 feet to over 300 feet.

The formation consists essentially of a very friable, white and pure quartz sand of well-rounded grains, which average coarser than those of the Mississippian.[113]

Photographs published by Cady[114] and by Sauer[115] show that bedding is much more prominent than cross-bedding, in the regions studied by them (Plates XXVII-XXVIII). Worthen says[116] "Distinct stratification exists in most of the outcrops, and even lines of cross stratification are not rare", from which one would certainly infer that bedding was more prominent than cross-bedding.

Ripple marks are said to be fairly abundant, and Worthen[117] suspects that they may be wind markings, though he does not describe any characteristics by which he reached this conclusion.

In the western part of the state, there is said to be a shaly bed near the middle of the formation.[118] Wells in Grundy county and Lake county[119] also reveal shale in the body of the St. Peter, and two wells in Lake county each penetrate 20 feet of dolomite with respectively 30 and 35 feet of St. Peter sandstone above and 150 feet and 90 feet of St. Peter sandstone below.

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[109] Leverett, Frank, Water resources of Illinois, p. 799.

[110] Weller, Stuart, The geological map of Illinois; Ill. Geol. Survey, Bull. No. 6, 1907, p. 15.

[111] Blatchley, R. S., Oil and gas in Bond, Macaupin and Montgomery Counties; Ill. Geol. Survey, Bull. No. 28, 1914, p. 36.

[112] Anderson, C. B., Artesian waters of Illinois, p. 84.

[113] Udden, J. A., Some deep borings in Illinois; Ill. Geol. Survey, Bull. No. 24, 1914, p. 28.

[114] Cady, G. H., Hennepin and LaSalle quadrangles, p. 39.

[115] Sauer, C. O., Geography of the Upper Illinois Valley; Ill. Geol. Survey; Bull. 27, 1916, p. 36.

[116] Worthen, A. H., Economical geology of Illinois; vol. III, 1882, p. 119.

[117] Worthen, A. H., Economical geology of Illinois, vol. III, pp. 18 and 129.

[118] Bartow, Edw., Udden, J. A., Parr, S. W., and Palmer, G. T., The mineral content of Illinois waters; Ill. Geol. Survey, Bull. No. 10, 1909, p. 14.

[119] Anderson, C. B., Artesian waters of Illinois, pp. 155, 185, 184, 186.

One is located at Grays Lake, the other at Lake Forest, about 8 miles apart. The cuttings were actually examined by members of the staff of the Illinois Survey, so that the data is as reliable as well data can ever be.

No fossils are reported from the St. Peter anywhere in Illinois.

Joachim.

The only place in Illinois where this formation is reported to outcrop, is along the Cap au Gres fault, in Calhoun county[120], where it reaches a thickness of about 75 feet, and is described as a buff, earthy, magnesian limestone, with occasional shaly layers. The only fossils reported are "one or more species of ostracods and one or two species of trilobites". Since this is practically continuous with exposures already described in Missouri, there is no doubt whatever of its equivalence with the Missouri Joachim.

Plattin-Platteville.

The only locality in Illinois where the term Plattin has been applied is in Calhoun county, where Weller[121] has used the Missouri name for beds next overlying the Joachim. There the Plattin is a close-textured drab limestone about 100 feet thick. No mention is made of unconformity between it and Joachim. The lower fifteen feet of the formation is said to carry very abundant remains of *Rafinesquina*, *Strophomena*, *Isotelus* and *Illaenus*, while the upper 20 feet contains *Dalmanella* (*Pionodema*) *subaequata* in great profusion.

The equivalent Platteville farther north in the state is not separated in many of the reports from the overlying Galena. The best detailed description of it is given by Shaw and Trowbridge.[122] They describe the formation as consisting of 40 feet of fine grained gray to blue limestone, with thin shale partings near the top. Fossils are abundant, and they list the following fauna:

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[120] Weller, Stuart, Geology of southern Calhoun County; Ill. Geol. Survey, Bull, No. 4, 1907, p. 222.

[121] Weller, Calhoun County, p. 222.

[122] Shaw, E. W., and Trowbridge, A. C., Galena-Elizabeth Folio; U. S. Geol. Survey, Folio 200, 1916.

Trowbridge, A. C., and Shaw, E. W., Geology and geography of the Galena and Elizabeth quadrangles; Ill. Geol. Survey, Bull. No. 26, 1916.

Platteville fauna.

	Range.
Thaleops ovatus Conrad	Bl. R.-Rich.
Leperditia fabulites Conrad	St. R.-Bl. R.
Protowarthia (Sinuites) rectangularis Ulrich	Bl. R.
Orthis (Dinorthis) deflecta Conrad	St. R.-Bl. R.
Orthis tricenaria Conrad	St. R.-Bl. R.
Orthis perverta Conrad (Pionodema subaequata perverta)	Bl. R.

From undifferentiated Platteville and Decorah are also listed the following forms.

Platteville and Decorah fauna.

	Range.
*Dalmanella (Pianodema) subaequata	St. R.-Bl. R.
*Zygospira recurvirostris.	Bl. R.-Tr.
Rafinesquina alternata	Tr.-Rich.
Plectambonites sericeus	Bl. R.-Rich.
*Dinorthis deflecta	St. R.-Bl. R.
Pterygometopus sp.	
Thaleops ovatus	Bl. R.-Rich.
*Streptelasma profundum	Bl. R.
*Leperditia fabulites	St. R.-Bl. R.
Stictoporella frondifera	Bl. R.
Stictoporella angularis	Bl. R.

This is clearly the equivalent of the Platteville of adjacent states, and apparently is to be correlated with the Plattin of Missouri and Arkansas, at least in part. It is dominantly Black River in its general relations.

There is reported slight unconformity[123] at least locally developed, between the Platteville and the St. Peter, channelings of at least two feet being described. Sauer[124] notes similar conditions. This unconformity may account for the presence of the Joachim between the St. Peter and Plattin farther south, though it is believed that in general the Joachim is more nearly synchronous with the top of the St. Peter to the north, and that it represents merging overlap. Not enough data are available to evaluate this break, though it is probable that it represents about the horizon of the Joachim-Plattin break of Missouri.

Decorah.[125]

Above the Platteville is a thin shale continuous with the Decorah of Iowa. It is much thinner in Illinois than farther west, rarely exceeding 10 feet. It consists of very thin-bedded limestone, with considerable shale. Fossils are moderately abundant, the following being especially characteristic:

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[123] Cady, G. H., Geology and mineral resources of the Hennepin and LaSalle quadrangles; Ill. Geol. Survey, Bull, No. 37, p. 39.

[124] Sauer, C. O., Geography of the Upper Illinois Valley; Ill. Geol. Survey, Bull. No. 29, 1916, p. 41.

[125] Shaw, E. W., and Trowbridge, A. C., Galena-Elizabeth quadrangles.

Decorah fauna.

	Range.
Buthograptus laxus	Bl. R.
Dalmanella minneapolis	
Stictoporella frondifera	Bl. R.
Stictoporella angularis	Bl. R.

Kimmswick-Galena.

The term Kimmswick has also been applied by Weller[126] in Calhoun county to beds next above the Plattin and continuous with the Kimmswick of Missouri. He describes it as a coarsely crystalline, light-colored, highly fossiliferous limestone, of which not over 50 feet are exposed in Calhoun county. It is particularly characterized by the abundance of *Receptaculites oweni.* It is essentially the equivalent of at least part of the Galena outcropping farther north in the state.

Savage[127] reports the Galena-Trenton, probably more properly the Kimmswick, of Alexander county, to consist of light colored crystalline limestone, of which not over 80 feet are exposed. They are the oldest beds to outcrop in that part of the state, and are immediately overlain by Maquoketa. From this horizon, he lists a considerable fauna.

Basal Galena-Trenton fauna from Alexander County.

	Range.
Receptaculitíes oweni	Bl. R.-Tr.
Hebertella near occidentalis	Mays.-Rich.
Parastrophia hemiplicata	Tr.
Platystrophia biforata	Ord.-Sil.
Rafinesquina alternata	Tr.-Rich.
Rhynchotrema inequivalve (increbescens)	Tr.
Strophomena emaciata	Tr.
Triplecia n. sp	
Bronteus (Goldius) lunatus	Tr.
Bumastus trentonensis	Tr.
Illaenus americanus	Tr.
Isotelus maximus	Tr.-Rich.
Platymetopus (Amphilichas) cucullus	Bl. R.-Tr.
Crania trentonensis	Tr.
Cyrtolites ornatus	Mays.-Rich.
Plectorthis plicatella	Mays.
Remopleurides striatulus	Tr.

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[126] Weller, Stuart, Calhoun County, p. 222.

[127] Savage, T. E., Stratigraphy of southwestern Illinois; Am. Jour. Sci., 4th ser., vol. XXV, 1908, pp. 431-443.

A number of these forms are said to persist into the upper part of the formation. This appears to be characteristic Trenton. Since it is just across the Mississippi river from typical Kimmswick in Missouri, likewise next below the Richmond, there would seem to be no doubt that this is a Kimmswick assemblage. It certainly does not bear out the claims made by some (pp. 33-34) that the Kimmswick is earlier than the Galena. The base of the Kimmswick does not appear to be exposed in this locality, and may quite possibly include Black River forms in its lower part, but the portion from which the fossils were collected is surely Trenton.

The Galena[128] of the northern part of the state rests next above the Decorah, is about 240 feet thick, and consists chiefly of coarse-grained crystalline dolomite of light bluish gray color, with occasional clay partings. The rock carries a considerable fauna.

Galena fauna from basal beds.

	Range.
Orthis tricenaria	St. R.-Bl. R.
Orthis (Dinorthis) pectinella	Bl. R.-Tr.
Orthis (Dalmanella) testudinaria	Bl. R.-Rich.
Plectambonites sericeus	Bl. R.-Rich.
Leptaena charlotta	Bl. R.
Rafinesquina alternata var	Tr.-Rich.
Strophomena incurvata var	St. R.-Bl. R.
Ctenodonta astartaeformis	Bl. R.
Vanuxemia niota	Bl. R.

Bumastus trentonensis and *Ceraurus pleurexanthemus* also occur in the lower beds. These lower beds appear to have a dominantly Black River fauna. Higher in the formation are two zones of *Receptaculites oweni*, one about 35 to 50 feet above the base, and one about 60 feet below the top of the formation. Additional forms are listed from the upper beds.

Galena fauna from the upper beds.

	Range.
Lingula iowensis	Tr.
Platystrophia biforata	Ord.-Sil.
Dalmanella testudinaria	Bl. R.-Rich.
Orthis tricenaria	St. R.-Bl. R.
Clitambonites diversa	Tr.-Rich.
Illaenus sp.	
Orthoceras amplicameratum	Bl. R. (?) Tr.
Triptoceras (Tripteroceras) lambi	Bl. R. Rich.
Receptaculites oweni	Bl. R.-Tr.

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[128] Shaw, E. W., and Trowbridge, A. C., Galena-Elizabeth quadrangles.

This list is not particularly good, but is more strongly Trenton than that from the lower beds. It would appear then, that the Galena ranges from latest Black River into Trenton, and it seems probable that the Kimmswick also includes both Black River and Trenton equivalents (pp. 33-38, 89).

Cady[129] does not separate the Platteville and Galena, but presents a list of fossils from the two horizons.

Fossils from Platteville-Galena.

	Range.
Receptaculites oweni Hall	Bl. R.-Tr.
Lingula near coburgensis	Chazy.
Orthis tricenaria Conrad	St. R.-Bl. R.
Platystrophia biforata Schlotheim	Ord.-Sil.
Dalmanella (Pianodema) subaequata var	St. R.-Bl. R.
Dalmanella testudinaria Dalman	Bl. R.-Rich.
Plectambonites sericeus Sowerby	Bl. R.-Rich.
Rafinesquina minnesotensis Winchell	Bl. R.
Strophomena incurvata Shepard	St. R.-Bl. R.
Strophomena cf. trentonensis	Tr.
Ctenodonta alta Hall	Tr.
Ctenodonta gibberula Salter	St. R.-Bl. R.
Rafinesquina alternata	Tr.-Rich.
Endodesma sp	
Cyclospira bisulcata Emmons	Tr.
Scenella cf. affinis	Bl. R.-Tr.
Scenella cf. compressa	Bl. R.
Bellerophon sp	
Tetranota sp	
Hormotoma gracilis Hall	Tr.-Rich.
Lophospira sp	
Trochonema cf. beachi	Bl. R.
Trochonema sp	
Raphistoma lenticulare Emmons (Liospira vitruvia)	Bl. R.-Rich.
Illaenus sp	

There is nothing particularly striking about this list. As would be expected, it contains characteristic forms from both Black River and Trenton.

It has already been pointed out (p. 33) that Ulrich reports a locality in Missouri, where he finds Galena resting on Kimmswick, from which he infers that the Galena is the younger. He places the Kimmswick in the Black River, and the Galena in the Trenton. According to Shaw and Trowbridge[130] both Weller and Ulrich agree that the main part of the Galena is younger than the Kimmswick. In this northern part of the state, however, in the Galena-Elizabeth quadrangles, the basal Galena appears to be essentially Black River (p. 90) while its upper part is Trenton. On the other hand, in Alexander county (p. 89) the Kimmswick, apparently some ways above its base, yields a highly typical Trenton assemblage of forms. Since, however, the Galena is considerably thicker than the Kimmswick, it is more than probable that the lower half of the Galena is approximately equivalent to the Kimmswick, the higher beds being absent in Missouri. This simply indicates a greater magnitude of the Trenton-Richmond break in the Ozark region, and is in keeping with the character of that area as a dominantly positive element. Still farther south, in Arkansas (p. 47) the Richmond rests on beds as old as Jasper, pointing to a break of considerable magnitude.

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[129] Cady, G. H., Geology and mineral resources of the Hennepin and LaSalle quadrangles; Ill. Geol. Survey, Bull. No. 37, 1919, p. 43.

[130] Galena-Elizabeth quadrangles.

Weller[131] calls attention to lithologic differences between the "Trenton-Galena" of Calhoun county (the Plattin and Kimmswick) and that of the rest of the state, and thinks that the faunas "are not entirely identical;" inferring that they belong to two separate provinces. It is not apparent, however, in fact not probable, that any barrier separated the two areas. The lower Galena is believed to be not only essentially synchromous with the Kimmswick, but also essentially continuous with it. As the region emerged, at the close of Trenton time, the Ozarks probably appeared first above water, the later Galena representing either an off-lap of beds never deposited in the Ozarks, or beds that have not been removed by erosion from the lower syncline of Illinois as effectively as from the dome of the Ozarks. The superposition of Galena on Kimmswick, in north Missouri would seem to represent merely an oblique transgression of certain lithologic facies.

Maquoketa.

Above the Galena[132] rests from 100 to 200 feet of shale, the continuation of a similar formation already described from Iowa. It consists chiefly of drab and bluish shale, with numerous beds of limestone. Fossils are very abundant.

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[131] Weller, Stuart, The geological map of Illinois; Ill. Geol. Survey, Bull. No. 6, 1907, p. 16.

[132] Shaw, E. W., and Trowbridge, A. C., Galena and Elizabeth quadrangles.

Fauna of basal Maquoketa.

	Range.
Zygospira modesta	Eden.-Rich.
Dalmanella testudinaria	Bl. R.-Rich.
Hindia parva	Bl. R.-Tr.
Hyolithes parviusculus	Rich.
Liospira micula	Tr.-Rich.
Pleurotomaria depauperata	Rich.
Clidophorus neglectus	Rich.
Ctenodonta fecunda	Rich.
Ctenodonta obliqua	Tr.-Rich.

Fauna of middle and upper Maquoketa.

	Range.
Monotrypella (Rhombotrypa) quadrata	Rich.
Monotrypa rectimuralis	Girardeau.
Heterotrypa (Dekayella) singularis	Rich.
Plectambonites saxea	Rich.
Leptaena unicostata	Rich.
Plectorthis whitfieldi	Rich.
Dinorthis subquadrata	Rich.
Platystrophia acutilirata var	Rich.
Rhynchotrema capax	Rich.
Rhynchotrema perlamellosa	Rich.
Rhynchotrema neenah	Rich.
Hebertella insculpta	Rich.
Hebertella occidentalis	Mays-.Rich.
Platystrophia biforata	Ord.-Sil.
Rafinesquina alternata	Tr.-Rich.
Dalmanella testudinaria	Bl. R.-Rich.
Plectambonites sericeus	Bl. R.-Rich.
Orthis anticostiensis (Dinorthis porcata anticostiensis)	Rich.
Hyolithis parviusculus	Rich.

This is the typical Maquoketa fauna of adjacent states of the upper Mississippi Valley. According to Weller[133], from 4 to 30 feet of typical Maquoketa overlies Richmond limestone (Fernvale) about 2 feet thick, in Monroe county, Illinois, and in St. Louis and Jefferson counties, Missouri. Savage[134] describes a peculiar phase of the Richmond in Alexander county, known as the Thebes sandstone and shale. The Thebes consists of a lower member of bluish sandstone, thin-bedded and shaly, about 75 feet thick, overlain by about 20 feet of bluish shale. The lower member is sparing fossiliferous, *Lingula* cf. *covingtonensis* occurring at several horizons. The upper shale carries more abundant organic remains, and from it the following fossils are reported.

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[133] Weller, Stuart, The pre-Richmond unconformity in the Mississippi Valley; Jour. Geol., vol. 15, 1907, pp. 519-525.

[134] Savage, T. E., Lower Paleozoic stratigraphy of southwestern Illinois; Am. Jour. Sci., 4th ser., vol. XXV, 1908, pp. 431-443.

Fauna of Thebes shale member.

	Range.
Cyclocystoides n. sp	Rich.
Phylloporina (Chasmatopora) near granistriata	Rich.
Dalmanella testudinaria	Bl. R.-Rich.
Plectambonites sericeus	Bl. R.-Rich.
Rhynchotrema inaequivalve?	Tr.
Strophomena sulcata ?	Rich.
Zygospira recurvirostris	Bl. R.-Tr.
Conradella (Phragmolites) near fimbriata	Bl. R.
Isotelus cf. susae or platycephalus	Bl. R.-Rich.

This fauna is not especially characteristic. Since, however, these beds rest above characteristic Trenton, in the position usually occupied by the Maquoketa, it is assigned to that formation by Savage. The overlying Cape Girardeau limestone was formerly assigned by Weller[135] to the Cincinnatian, but Savage has shown it to be Silurian. Particular interest attaches to the Thebes, because it is so much coarser clastic material than equivalent beds farther north. Throughout the Ordovician there has appeared a very consistent decrease in the amount of clastic material, and increase in the lime content of formations, southward from Wisconsin toward Missouri. The Thebes appears to be the only important exception to this general principle, and suggests a local source. As has already been pointed out (p. 92), the Ozark region seems to have been land for a longer time, during the Trenton-Richmond break, than adjacent areas were, and the removal of a considerable thickness of limestone from the Ozark area might have yielded enough sand and clay to have given deposits as local as the Thebes appears to have been. It is quite possible that these deposits lie close to the mouth of an old river, draining the Ozark Island, which probably never was completely submerged beneath the Richmond sea. The presence of sand is a little surprising, however, unless erosion cut deeply enough to expose the St. Peter, and this hardly seems probable.

According to Shaw and Trowbridge[136] there are indications of a break between the Galena and Maquoketa, but the proofs are not conclusive. Their statement that the topmost member of the Galena, carrying *Lingula iowensis*, seems to be absent at places, strongly suggests such an interpretation, as does also the presence of an oxidized zone, and phosphatic nodules at this horizon. Weller[137] presents conclusive proofs that such an unconformity exists, and that the physical evidence can be found in the field, in the nature of actual erosion surfaces, residual soil, and overlap of the Richmond across various horizons of the Kimmswick.

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[135] Weller, Stuart, The geological map of Illinois; Ill. Geol. Survey, Bull. No. 6, 1907, pp. 17-18.

[136] Galena-Elizabeth quadrangles.

MINNESOTA.

Oneota.

The oldest formation in Minnesota to be assigned to the Ordovician is the Oneota. It is the same horizon that is termed "Lower Magnesian" in certain of the Minnesota reports[138], but care must be used in interpreting old references, since "Lower Magnesian" was used by the Wisconsin geologists to include the entire Prairie du Chien group, that is, the Oneota, New Richmond, and Shakopee. Attention must also be called to the fact that in some of the Minnesota reports, the Oneota was confused with the St. Lawrence[139], a term now confined to lower beds. As restricted at present, the Oneota overlies the Jordan sandstone, and underlies the New Richmond.

It varies from about 75 to 175 feet in thickness, and consists essentially of a cherty gray to buff dolomite, varying from crystalline to compact, but characteristically rather coarse granular and cavernous. A few thin sandstone beds occur near the base and near the top. Fossils are not abundant but the following species are listed by Sardeson[140].

Oneota fauna.

	Range.
Asaphus sp	
Lingula (Obolus) dolata n. sp	**Oneota.**
Lingula (Lingulella) mosia Hall	**U. C.-Oneota.**
Orthis pepina Hall (Billingsella coloradoensis)	**M. C.-Oneota.**
Euomphalus winonensis n. sp	**Oneota.**
Holopea (Sinuopea) obesa Whitfield	**Oneota.**
Murchisonia putilla n. sp	**Oneota.**

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[137] Weller, Stuart, The pre-Richmond unconformity in the Mississippi Valley; Jour. Geol., vol. 15, 1907. pp. 519-525.

[138] Geol. and Nat. Hist. Survey of Minn., vol. 2, 1882-85, p. 12.

[139] Geol. and Nat. Hist. Survey of Minn., vol. I, 1872-82, p. 222, also Minn. Acad. Sci., Bull. 4, 1892-1910, pp. 119-123.

[140] Sardeson, F. W., U. S. Geol. Survey, Minneapolis-St. Paul Folio; No. 207, 1916; also Minn. Acad. Sci., Bull. 4, 1892-1910, p. 94.

	Range.
Ophileta alturensis n. sp	Oneota.
Raphistoma leisomellum n. sp	Oneota.
Raphistoma minnesotense Owen	Oneota.
Raphistoma oweni n. sp	Oneota.
Straparollus interlobatus n. sp	Oneota.
Ascoceras gibberosum n. sp	Oneota.
Cyrtoceras dresbachense n. sp	Oneota.
Cyrtoceras winonicum n. sp	Oneota.
Piloceras coniculum n. sp	Oneota.

Most of these species are found only in the Oneota of Minnesota and adjacent states. The only two species known from other horizons are characteristic Cambrian forms. On the other hand, most of the genera are more abundant in higher beds. The Oneota is continuous with that formation in Iowa, Wisconsin, and Illinois, and on the basis of its physical character, its stratigraphic position, and its continuity, as shown by well records, is surely the equivalent of the Gasconade of Missouri. Sardeson includes it in the Ordovician, as do the Iowa geologists. Ulrich draws the base of the Beekmantown, however, at the base of the New Richmond.

New Richmond.

This formation, as now defined, is restricted to a mixed sandstone and dolomite horizon, resting between the Oneota below and the Shakopee above. In some of the older reports the term Jordan was applied to these beds[141], though this term is now restricted to lower horizons. In some sections New Richmond is not recognized at all[142] and it reaches its maximum thickness in the southern part of the state, where it is said to average about 40 feet[143]. In Blue Earth county 75 feet of Jordan is reported,[144] beneath Shakopee. This is more probably, however, true Jordan, beneath Oneota.[145] The greatest thickness reported for the New Richmond is 80 feet[146]. The sandstone is rather pure and white as encountered in wells, but is more iron-stained on the outcrop. According to repeated statements, it closely resembles the St. Peter, for which it is likely to be mistaken.

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[141] Minn. Geol. and Nat. Hist. Survey, vol. 2, 1882-85, p. 11, foot note, also Minn. Acad. Sci., Bull. 4, 1892-1910, pp. 119-123.

[142] Folio 201.

[143] Hall, C. W., Meinzer, E. O., and Fuller, M. L., Geology and underground waters of southern Minnesota; U. S. Geol. Survey, Water Supply Paper No. 256, 1911, pp. 45-46.

[144] Geol. and Hat. Nist. Survey of Minn. vol. 1, 1872-82, p. 427.

[145] Water Supply Paper No. 256, p. 140.

[146] Water Supply Paper No. 256, p. 328.

Gradation of the sandstone laterally into chert and limestone is reported, resulting in great difficulty in drawing the line between it and Oneota[147]. This condition is probably responsible for the reported sudden variations in thickness, and for the seeming absence of the sandstone in certain sections. The formation is continuous with the New Richmond in Wisconsin, Iowa, and Illinois, and with the Roubidoux of Missouri, with which it is correlated not only on the basis of continuity, as shown by well records, but also by its stratigraphic position and lithologic character. So far as the writer can discover, no fossils are reported from this horizon in Minnesota.

Shakopee.

This formation occupies a position above the New Richmond and below the St. Peter. It consists of gray to buff cherty dolomite, with occasional thin sandstone layers, and is finer grained, on the average, than the Oneota. The thickness varies from 25 to 60 feet. The variation may in part be the result of failure to differentiate the New Richmond below, but is doubtless also in part the result of the unevenly eroded surface of the Shakopee, beneath the St. Peter. Winchell[148] says:

> "It seems probable that the upper surface of the 'Lower Magnesian' suffered some great erosion before deposition of the St. Peter sandstone, and whether this accounts for the absence of the Richmond and Shakopee beds in some places, and their presence in others, it is not possible to state unqualifiedly, but it is a reasonable hypothesis."

As already shown (pp. 67, 112) this is known to be the situation in Iowa and Wisconsin. A small fauna is described from the Shakopee.[149]

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[147] Geol. and Nat. Hist. Survey of Minn., vol. 2, 1882-1885, p. 37.

[148] Winchell, N. H., The geology of Washington County; Geol. and Nat. Hist. Survey of Minn., vol. 2, 1882-85.

[149] Sardeson, F. W., The fauna of the Magnesian Series; Minn. Acad. Sci., Bull. 4, 1892-1910, pp. 92-105. Also Folio 201.

Shakopee fauna.

	Range.
Eccyliomphalus sp	
Raphistoma ruidum	Shak.
Hormotoma (Murchisonia) argylensis	Shak.
Trochonema (Helicotoma) pecatonica	Shak.
Fusispira (Subulites) exacta	Shak.
Endoceras consuetum	Beek.
Eurystomites kellogi	Ft. Cassin.
Raphistoma lewistonense	Shak.
Triblidium ? repertum	Shak.

This assemblage is characteristic also of Shakopee in Wisconsin, and carries two typical Beekmantown forms.

St. Peter.

The St. Peter rests next above the Shakopee, and in spite of the repeated statements of conformability between the two, advanced perhaps most recently by Sardeson,[150] there is abundant evidence of erosion at the contact, in adjacent states; and even in Minnesota, the oxidized condition of the limestone next below the St. Peter[151] suggests the presence of a break, as do also the variations in thickness of both St. Peter and Shakopee. Winchell has suggested (p. 97) that pre-St. Peter erosion may have removed both Shakopee and New Richmond thus accounting for their apparent absence in certain sections. The fact that the uncomformable relations between the two have been so well proved in other states makes it very difficult, moreover, to believe that the two can possibly be conformable in Minnesota, when every other known paleogeographic condition points to the north and northwest as the source of the sand, and therefore suggests the greater emergence in that direction.

Certain dome-like structures in the underlying Shakopee, which appear in part at least to be the basis for statements concerning pre-St. Peter folding (pp. 113-114), are now ascribed by Sardeson[152] to reef-like structures, probably Cryptozoon reefs. In spite of very positive assertions of folding during the pre-St. Peter emergence, or during St. Peter deposition,[153] there appears to be no convincing evidence of such deformation. Sardeson[154] himself now ascribes much of the apparent folding to solution and consequent readjustment. He says:

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[150] Folio 201. See also Hall, C. W., and Sardeson, F. W., Paleozoic formations of southeastern Minnesota; Bull. Geol. Soc. America, vol. 3, 1892, pp. 331-368.

[151] Hall, C. W., Artesian well borings in southeastern Minnesota; Minn. Acad. Sci., Bull. 3, 1883-91, pp. 128-143.

[152] Folio 201.

[153] Hall and Sardeson; Bull. Geol. Soc. America, vol. 3, p. 353; also Sardeson, Minn. Acad. Sci., Bull. 3, p. 81.

> "In the opinion of the author, the St. Peter sandstone was laid down horizontally and conformably on a level surface of the Shakopee dolomite and was covered conformably by the beds of the Platteville limestone. At a later time the leaching of the sandstone and the solution of constituents from the underlying formations produced a gradual settling and distortion in the base of the St. Peter and the underlying dolomite."

The St. Peter is made up of medium to fairly coarse-grained sandstones, very pure, consisting of well-rounded quartz grains. Cross-bedding has been reported, but a careful study of many descriptions gives a decided impression that bedding is the more prominent, and this impression is strengthened by a study of the photographs (Plates XXIX-XXX) published by Sardeson[155] who, moreover, states that such cross-bedding as was noted is that of a water-laid deposit, rather than of the eolian type. He also points out that the formation is of less uniform grain than is usually appreciated, ranging in size "from dust to particles a millemeter or more in diameter". This appears to be a somewhat larger maximum size than the writer noted in his Missouri studies, and is in consonance with the idea that it is nearer its source. He also calls attention to the fact that the base is less pure than the rest of the formation, containing shaly beds. This condition was noted by the writer in Missouri, and ascribed to the inclusion of old clay soils, from the erosion surface of the Shakopee, on which the sand was laid down.

The formation varies from 80 to 200 feet in thickness[156] and locally there is a bed of shale about 40 feet above the base, of sufficient importance to confine the waters under artesian pressures, even where dissection has cut well into the upper part of the sandstone. There are said to be other shale partings in the lower third of the formation.

The St. Peter is sparingly fossiliferous near St. Paul, and Sardeson has collected and identified a considerable fauna,[157] a large proportion of which came from a horizon about 80 feet below the top, while other specimens were collected at two still lower horizons. Fossils were also reported at the very top. The complete list follows.

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[154] Folio 201.

[155] Folio 201.

[156] Water Supply Paper 256, pp. 44-45, and 199.

[157] Sardeson, F. W., The St. Peter sandstone: Minn. Acad. Sci. Bull. 4, 1892-1910, pp. 64-87.

Fauna of the St. Peter sandstone.

Cypricardites (Vanuxemia) fragosus n. sp.
Cypricardites descriptus n. sp.
Cypricardites finitimus n. sp.
Cypricardites dignus n. sp.
Modiolopsis fountainensis n. sp.
Modiolopsis postica n. sp.
Modiolopsis litoralis n. sp.
Modiolopsis contigua n. sp.
Modiolopsis gregalis n. sp.
Modiolopsis affinis n. sp.
Modiolopis senecta n. sp.
Tellinomya novicia n. sp.
Tellinomya absimilis n. sp.
Holopea paludiniformis Hall.
Holopea cf. obliqua Hall.
Murchisonia cf. gracilis Hall.
Murchisonia cf. tricarinata Hall.
Ophileta fausta n. sp.
Platyceras vetulum n. sp.
Pleurotomaria aiens n. sp.
Orthoceras (?) sp. undet.
Orthoceras sp. undet.
? Crania reversa n. sp.
Lingula morsii N. H. Winchell.
Orthis preverta (?) Conrad.
Ptilodictya (?) sp. ?
Raufella (?) fucoida n. sp.
Orthoceras minnesotense n. sp.

There are of

Pelecypods	3 genera and 13 species.
Gastropods	5 genera and 7 species.
Cephalopods	1 genus and 3 species.
Brachiopods	3 genera and 3 species.
Bryozoa	1 genus and 1 species.
Sponges	1 genus and 1 species.
Total	14 genera and 28 species.

So large a proportion of these are new species that exact correlations are not possible. Of special interest, however, is the state of preservation. The shells were too complete and unbroken to have been carried far by waves, the valves evidently not having been broken apart, in some cases. But not a trace of the calcareous shells remained, in any case, the fossils showing only as smooth cleavage planes in the sand. Such fossils would not be seen at all, except under very favorable conditions.

The regularity and continuity of the interbedded shale layer and the presence of marine fossils over 80 feet below the top of the formation suggest deposition in water, rather than mere working over by waves of a wind-laid deposit.

The distribution of the St. Peter in the state is of interest in its bearing on the position of the border of the land mass from which the sediment was derived. A line drawn from the city of St. Paul due southwest will approximate closely the northwestern border of the formation in Minnesota. Southeast of this line, the St. Peter is very generally present whether deeply buried below younger sediments, as over most of the area, or exposed in outcrop. Very locally it is removed, exposing older beds. Northwest of this line, older Paleozoic or pre-Cambrian is either exposed or immediately underlies the Cretaceous.

As this border is approached there is no apparent change in the character or thickness of the St. Peter, consonant with the idea of a nearby crystalline land mass of mixed character. In Hennepin county, there is a thickness of about 175 feet of highly characteristic white sandstone. In Sherburn, Wright and Carver counties, immediately to the north and west, the surface rocks are older Paleozoic, the St. Peter being cut off. In Scott county, 110 feet of typical St. Peter is reported, while in Sibley county, to the west, the youngest Paleozoic formation encountered seems to be the Jordan. In Le Sueur county, the St. Peter is 100 feet thick, and apparently of the familiar type, while in Nicollet county, next on the west, the Prairie du Chien comes to the surface. In Blue Earth county, the St. Peter does not outcrop, but wells have penetrated it about 100 feet. In these wells it shows its usual qualities. In Brown county to the west, Cretaceous overlies probable Dresbach in the southeast corner, passing across onto pre-Cambrian farther west, and similarly in Watonwan county, the Cretaceous rests on older Paleozoic beds in the eastern half, while to the west, the pre-Cambrian directly underlies the Cretaceous. In Faribault county there are 90 feet of typical St. Peter, while in Martin county, on the west, are 100 feet of white sandstone, doubtfully assigned to the same formation. West of that, in Jackson county, Cretaceous again rests on pre-Cambrian.[158]

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[158] These data are from Water Supply Paper 256.

This fits well with the facts of distribution in northwestern Iowa, where the undiminished thickness of typical St. Peter extends quite to the limit of its present extent. The situation appears to have been that the St. Peter once extended much farther northwest than now, but was tilted to the southeast and planed across by erosion sometime previous to the Cretaceous, and possibly before the Carboniferous.

Platteville.

This formation, which rests on the St. Peter without visible evidence of intervening erosion, averages not far from 30 feet thick, and consists of thin-bedded buff to bluish-gray limestone, with occasional thin shale partings. It is abundantly fossiliferous, and the following fauna is reported from the formation in the St. Paul-Minneapolis area.[159]

Platteville fauna.

	Range.
Hindiā parva	Bl. R.
Asaphus (Isotelus) gigas	Bl. R.-Rich.
Bumastus trentonensis	Tr.
Dalmanites (Pterygometopus) callicephalus	Tr.
Ceraurus pleurexanthemus	Bl. R.-Tr.
Conchicolites (Cornulites) minor	Mays.
Conradella (Phragmolites) compressa	Tr.
Lophospira conradana	Bl. R.
Lingula iowensis	Tr.
Crania setigera	Bl. R.
*Strophomena filitexta (incurvata)	St. R.-Bl. R.
*Orthis tricenaria	St. R.-Bl. R.
Hebertella bellarugosa	Chazy-Bl. R.
*Zygospira recurvirostris	Bl. R.-Tr.
Escharopora subrecta	Bl. R.
Rhinidictya mutabalis	Bl. R.-Tr.
Hallopora multitabulata	
*Streptelasma profundum	Bl. R.

Sardeson[160] also lists another assemblage of "Trenton" forms:

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[159] Folio 201.

[160] Sardeson, F. W., The lower Silurian formations of Wisconsin and Minnesota compared; Minn. Acad. Sci., Bull. 3, 1883-91, pp. 319-343.

"*Trenton*" *fauna* (*Platteville*).

	Range.
*Orthis (Pianodema) subaequata Con	St. R.-Bl. R.
*Orthis (Dinorthis) deflecta Con	St. R.-Bl. R.
Rhynchonella (Camarotoechia) orientalis Bill	Chazy.
Strophomena (Rafinesquina) minnesotensis Winchell (var)	Bl. R.
Ambonychia attenuata Hall (Clionychia lamellosa)	Bl. R.
Orthis preverta Con. (Pianodema subaequata perverta)	Bl. R.
Trochonema beloitense Whitf.	Bl. R.
Cypricardites (Vanuxemia) rectirostris Hall	Bl. R.
Crania granulosa N. H. Winchell	Bl. R.
Crania trentonensis Hall	Tr.
Discinia concordensis (Scizotreta pelopea)	Tr.-Rich.
Leptaena (Plectambonites) sericea Sowerby	Bl. R.-Rich.
Lingula elderi Whitfield	Bl. R.
Lingulella (Lingula) iowensis	Tr.
Orthis (Hebertella) bellarugosa	Chazy-Bl. R.
Rhynchonella (Rhynchotrema) minnesotensis n. sp	Bl. R.
Skenidium (Scenidium) anthonensis n. sp	Bl. R.
*Streptorhynchus convexus Owen (Strophomena incurvata)	St. R.-Bl. R.
Streptorhynchus filitextum Hall (Strophomena incurvata)	
Zygospira aquila n. sp. (nicolleti)	Bl. R.
Bucania (Tetranota) bidorsata Hall	St. R.-Tr.
Holopea paludiniformis Hall.	St. P. ?-Tr.
*Helicotoma planulata Slater	Bl. R.
Maclurea (Maclurites) bigsbyi Hall	Bl. R.
*Metoptoma (Archinacella) billingsi Walcott	Low.
Metoptoma explanata (Archinacella perovalis)	Bl. R.
*Murchisonia milleri Hall (Lophospira bicincta)	St. R.-Rich.
Murchisonia (Hormotoma) gracilis Hall,	Tr.-Rich.
Murchisonia (Lophospira) ventricosa Hall	Bl. R.
Murchisonia (Lophospira) tricarinata Hall	Bl. R.
Raphistoma lenticulare Emmons (Liospira vitruvia)	Bl. R.-Rich.
Raphistoma nasoni Hall (Eotomaria supracingulata)	Bl. R.
Subulites elongatus Emmons	Tr.
Trochonema umbilicatum Hall	Bl. R.-Tr.
Tryblidium (Stenotheca) exsertas n. sp	Bl. R.
Cypricardites vicinus n. sp. (Vanuxemia obtusifrons)	Bl. R.
Modiolopsis meyeri Billings	Tr.
Modiolopsis (Eurymya) plana Hall.	Bl. R.
*Tellinomya (Ctenodonta) nasuta Hall	Bl. R -Tr.
Tellinomya (Ctenodonta) caudens n. sp	Bl. R.
*Tellinomya ventricosa (Ctenodonta gibberula)	St. R.-Bl. R.

This is a characteristic fauna, largely duplicated in the formation in adjacent states, and sufficient to correlate the Platteville with the Plattin of Missouri, and with the Black River of the standard section.

According to Bassler's "Index", about a dozen of these forms (those marked with a star) are described from the Lowville or its definite equivalents in other regions. Unfortunately they are not especially characteristic of the Lowville, nor are they limited to that horizon. Therefore it is not possible to say with assurance that the Lowville is present. The thickness of the Platteville (30 feet) and the Decorah (60 feet) taken together, however, is in excess of the type Lowville-Black River section, and it is therefore reasonable to assume that the Lowville equivalent is contained in the base of the Platteville formation.

Bierbauer[161] lists other "Trenton" forms, but it is very difficult to tell whether his "Trenton", and "Galena" correspond to Platteville and Galena as the terms are now used. It is quite probable that they do not, and since he gives no localities, and no sections, it is almost impossible to evaluate his list, beyond the fact that his Trenton and Galena combined are equal to the more recent Platteville, Decorah and Galena combined.

Decorah.

This horizon, which corresponds to the "Green Shale" of the earlier workers, is especially well-developed in the vicinity of St. Paul and Minneapolis,[162] where it reaches a thickness of over 60 feet, about one-fifth of which consists of occasional thin limestone beds, in a typical clay shale. Locally, it is said to be[163] nearly 50 per cent crystalline limestone, in thin beds with shale.

In Goodhue county[164] the "Green Shale" is reported to reach an average of 100 feet. It must be noted, however, that in a few cases, this horizon has probably been confused with the Maquoketa.

The following faunal list is compiled from a number of sources[165], in all of which there seems to have been much care to collect and list from definite horizons within specified limits:

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[161] Bierbauer, Bruno, A check list of the Paleozoic fossils of Wisconsin, Minnesota, Iowa, Dakota and Nebraska; Minn. Acad. Sci., Bull. 3, 1883-91, pp. 206-247.

[162] Folio 201, also Minn. Acad. Sci., Bull. 3, pp. 319-343.

[163] Water Supply Paper 256, p. 44.

[164] Geol. and Nat. Hist. Survey of Minn., vol. 2, p. 40.

[165] Sardeson, Minn. Acad. Sci., Bull 3, pp. 319-343.
Sardeson, Folio 201.
Hall and Sardeson, Bull. Geol. Soc. America, vol. 3, p. 364.
Sardeson, American Geologist, vol. 18, 1896, and vol. 19, 1897.

Decorah fauna.

	Range.
*Plectambonites minnesotensis Sard	Tr.
Plectambonites sericeus Sowerby	Bl. R.-Rich.
Orthis (Pianodema) subaequata var. gibbosa Bill	Bl. R.
Anoloteichia impolita Ulr	Bl. R.
Pachydictya foliata Ulr	Bl. R.
Stictoporella frondifera Ulr	Bl. R.
Rhynchotrema minnesotensis Sard	Bl. R.
Rhynchonella (Rhynchotrema) ainsliei Winchell	Bl. R.
Orthis (Dalmanella) testudinaria Dal	Bl. R.-Rich.
*Orthis tricenaria Con	St. R.-Bl. R.
Stictopora (Rhinidictya) mutabilis Ulr	Bl. R.
Phylloporina (Chasmatopora) corticosa Ulr	Bl. R.
Orthis (Dinorthis) pectinella Con	Bl. R.-Tr.
*Zygospira recurvirostris Hall	Bl. R.-Tr.
*Orthisina americana Whitf. (Clitambonites diversus)	Tr.-Rich.
*Receptaculites oweni Hall	Bl. R.-Tr.
*Receptaculites (Ischadites) iowensis Owen	Tr.
*Pachydictya occidentalis Ulrich	Bl. R.
*Orthis (Dalmanella) rogota Sardeson	Bl. R.-Tr.
*Rhynchonella (Rhynchotrema) increbescens Hall	Tr.
Crania halli n. sp. (Petrocrania ulrichi)	Bl. R.
Crania setigera Hall	Bl. R.
Lingula elderi Whitfield	Bl. R.
*Lingula riciniformis (?) Hall	Tr.
Orthis (Hebertella) bellarugosa Conrad	Chazy-Bl. R.
*Orthis (Platystrophia) biforata Schlotheim	Ord.-Sil.
*Orthis minnesotensis n. sp. (Dinorthis meedsi)	Tr.
Orthis perverta Conrad (Pianodema subaequata perverta)	Bl. R.
Orthis (Plectorthis) plicatella Hall	Mays
*Pholidops trentonensis (?) Hall	Tr.
Productella minneapolis n. sp. (Trematis huronensis)	Bl. R.
Rhynchonella santa n. sp. (Rhynchotrema increbescens laticostatum)	Tr.
Streptorhynchus convexus Owen (Strophomena incurvata)	St. R.-Bl. R.
*Streptorhynchus filitextum Hall (Strophomena incurvata)	St. R.-Bl. R.
*Streptorhynchus subsulcatum n. sp. (Strophomena scofieldi)	Tr.
*Strophomena (Rafinesquina) alternata Conrad	Tr.-Rich.
Strophomena camarata Conrad (Rafinesquina deltoidea)	Tr.
Strophomena inquassa n. sp. (Rafinesquina minnesotensis inquassa)	Bl. R.
Strophomena halli n. sp. (Leptaena charlottae)	Bl. R.
*Bellerophon bilobatus Sowerby (Sinuites cancellatus)	Tr.-Rich.
*Bucania (Tetranota) bidorsata Hall	St. R.-Tr.
*Bucania (Salpingostoma) buelli Whitfield	Bl. R.
*Bucania punctifrons Emmons	Tr.
Carinaropsis (Archinacella) deleta n. sp	Bl. R.
Carinaropsis phalera n. sp	Bl. R.
Conchopeltis (Scenella) obtusa n. sp	Bl. R.
Cyclonema montrealense Billings	Tr.
Cyclonema (Gyronema) semicarinatum Salter	Bl. R.
Cyclonema (Gyronema) percarinatum Hall	Tr.
*Fusispira elongata Hall	Tr.
Fusispira spicula n. sp	Bl. R.
Holopea obliqua Hall	St. P. ? Tr.
Holopea paludiniformis Hall	St. P. ? Tr.
*Holopea perundosa n. sp. (pyrene)	Bl. R.-Tr.
Holopea symmetrica Hall	Tr.
Helicotoma planulata Salter	Bl. R.

	Range.
*Murchisonia (Omospira) alexandria Billings	Bl. R.
*Murchisonia (Hormotoma) bellacincta Hall	Tr.
*Murchisonia (Hormotoma) gracilis Hall	Tr.-Rich.
*Murchisonia milleri Hall (Lophospira bicincta)	St. R.-Rich
Murchisonia (Lophospira) ventricosa Hall	Bl. R.
Murchisonia (Lophospira) tricarinata Hall	Bl. R.
Pleurotomaria (Trochonema) clivosa n. sp	Bl. R.
Pleurotomaria (Clathrospira) subconica Hall	Bl. R.-Tr.
*Raphistoma lenticulare Emmons (Liospira vitruvia)	Bl. R.-Rich.
*Subulites elongatus Emmons	Tr.
Trochonema beachi Whitfield	Bl. R.
Trochonema beloitense Whitfield	Bl. R.
*Trochonema umbilicatum Hall	Bl. R.-Tr.
Tryblidium (Archinacella) validus n. sp	Tr.
Cypricardites (Cyrtodonta) canadensis Billings	Bl. R.
Cypricardites minnesotensis n. sp. (Cyrtodonta glabella)	Bl. R.
Cypricardites (Vanuxemia) niota Hall	Bl. R.
Cypricardites (Vanuxemia) rotundatus Hall	Bl. R.
Cypricardites subtruncatus Hall	?
Cypricardites triangularis n. sp. (Vanuxemia hayniana)	Tr.
Modiolopsis (Colpomya) faba Emmons	Tr.
Modiolopsis meyeri Billings	Tr.
Modiolopsis (Eurymya) plana Hall	Bl. R.
Modiolopsis rectiformis Worthen (Endodesma orthonotum)	Bl. R.
Tellinomya (Ctenodonta) candens n. sp	Bl. R.
*Tellinomya (Ctenodonta) astartaeformis Salter	Bl. R.
Tellinomya (Ctenodonta) levata Hall	Tr.
Tellinomya ventricosa (Ctenodonta gibberula)	St. R.-Bl. R.
Whitella compressa Ulrich	Bl. R.

The list contains many forms characteristic of the Decorah in adjacent states, and is strongly Black River in aspect. The forms that are prefixed with a star, while a few of them are found in the lower and the middle of the Decorah, are more characteristic of the horizon known as the "Orthisina Bed." This has been variously placed in the Decorah and the Galena. Lithologically it is a very shaly horizon, resembling more closely the Decorah than the Galena, while its faunal affinities are with both. Of about thirty starred species, thirteen do not elsewhere range below Trenton, while 6 do not elsewhere range higher than Black River, and several forms are found widely in both. It is, however, of chief interest to note that it is a lithologic phase of the Decorah, with a strongly Trenton assemblage of forms. The proper interpretation would seem to be that the Galena at its base passes from typical limestone in Wisconsin and Illinois by lateral gradation into shale to the northwest, in full accord with other facts that point to a land mass in that direction. In Missouri the residual material from which the most extensive Decorah fauna has been secured is a chert (the Auburn chert) suggesting that the Decorah there is chiefly limestone; and this also suggests derivation from a general northerly direction.

Galena.

The Galena formation, which overlies the Decorah, attains a thickness of over 100 feet at least, in the state. It consists chiefly of dolomitic limestone, from earthy to crystalline, usually well-bedded, with frequent shale partings.

Winchell[166] points out that the Galena formation, in Minnesota, "changes gradually toward the north, by acquiring shale." He seems to have reference to the increase in the Decorah to the northwest, which he interprets as a gradation phase of the Galena, in the nature of merging overlap, as suggested under the description of the Decorah.

Sardeson[167] lists a considerable fauna.

Fauna of the Galena.

	Range.
Pachydictya acuta Hall	Tr.
Hallopera multitabulata Ulrich	Bl. R.-Tr.
Camarella bernensis n. sp. (Parastrophia hemiplicata)	Tr.
Camarella hemiplicata Hall (Parastrophia hemiplicata)	Tr.
Camarella owatonensis n. sp. (Cyclospira bisulcata)	Tr.
Crania trentonensis Hall	Tr.
Discina concordensis n. sp. (Schizotreta pelopea)	Tr.-Rich.
Leptaena (Plectambonites) minnesotensis n. sp	Tr.
Lingulasma schucherti (?) Ulrich	Rich.
Lingulella (Lingula) iowensis Owen	Tr.
Orthis (Hebertella) bellarugosa Conrad	Chazy-Bl. R.
Orthis (Platystrophia) biforata Scholtheim	Ord.-Sil.
Orthis (Plectorthis) plicatella Hall	Mays.
Orthis (Dalmanella) rogata n. sp	Bl. R.-Tr.
Orthis tricenaria Conrad	St. R.-Bl. R.
Orthisina americana Whitfield (Clitambonites diversus)	Tr.-Rich.
Rhynchonella (Rhynchotrema) increbescens Hall	Tr.
Streptorhynchus (Strophomena) trilobatum Owen	Tr.
Strophomena (Rafinesquina) alternata Conrad	Tr.-Rich.
Strophomena camarata (Rafinesquina deltoidea)	Tr.
Strophomena tenuistriata Winchell (Leptaena richmondensis)	Rich.
Zygospira recurvirostris Hall	Bl. R.-Tr.
Bellerophon bilobatus Sowerby (Sinultes cancellatus)	Tr.-Rich.
Bucania punctifrons Emmons	Tr.
Fusispira elongata Hall	Tr.

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[166] Winchell, N. H., The age of the Galena limestone; American Geologist, vol. 15, 1885, pp. 33-39.

[167] Folio 201, and Minn. Acad. Sci., Bull. 3, pp. 319-343; also American Geologist, vol. 19, 1897, pp. 21-35, 91-110, 181-190, 330-336; and Bull. Geol. Soc. America, vol. 3, pp. 331-368.

	Range.
Fusispira ventricosa Hall	Tr.
Maclurea (Maclurina) cuneata Whitf	Tr.
Murchisonia (Hormotoma) major Hall	Tr.
Raphistoma lenticulare Emmons (Liospira vitruvia)	Bl. R.-Rich.
Modiolopsis modiolaris Hall	Cin.
Receptaculites oweni Hall	Bl. R.-Tr.

This fauna serves to correlate the Galena of Minnesota with that of adjacent states, and shows a dominantly Trenton aspect here as elsewhere.

Maquoketa.

This formation[168] has been described as consisting of interbedded shales and crystalline limestones varying in thickness up to perhaps 20 feet, excluding the Wykoff. In the older reports[169] this seems to have been termed "Green Shale" and confused with the Decorah. It does not appear to be definitely recognized much beyond the borders of Fillmore, Olmsted, Dodge and Mower counties, in the extreme southeastern part of the state. The following fauna has been described by Sardeson.[170]

Maquoketa fauna.

	Range.
Leptaena (Plectambonites) praecosis n. sp	Maq. of Minn.
Orthis (Dalmanella) corpulenta n. sp	Maq. of Minn.
Streptorhynchus (Strophomena) trilobatum Owen	Tr.
Strophomena tenuistriata Sowerby (Leptaena richmondensis)	Rich.
Strophomena (Rafinesquina) alternata (?) Hall	Tr.-Rich.
Strophomena (Leptaena) unicostata M. and W.	Rich.

This fauna is too limited to be very characteristic, but there is no doubt that these beds are continuous with the Maquoketa of adjacent states, and are of Richmond age.

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[168] Minn. Acad. Sci., Bull. 3, pp. 319-343.

[169] Geol. and Nat. Hist. Survey of Minn., vol. 1, pp. 218, 289.

[170] Minn. Acad. Sci. Bull. 3, pp. 319-343.
American Geologist, vol. 18, 1896,pp. 354-368.
American Geologist, vol. 19, 1897, pp. 21-55, 91-110, 181-190, 330-336.
Bull. Geol. Soc. America, vol. 3, pp. 331-368.

Wykoff

Above the Maquoketa, in Minnesota, rests from 50 to 70 feet of very fossiliferous limestone to which Hall and Sardeson[171] have given the above name. They list the following fauna:

Wykoff fauna.

	Range.
Leptaena (Plectambonites) recedens n. sp	Maq. of Minn.
Lingula elderi Whitfield	Bl. R. of Minn. and Wis.
Orthis (Dalmanella) corpulenta n. sp	Maq. of Minn.
Orthis (Plectorthis) kankakensis McChesney	Fernv. of Ill.
Orthis (Dalmanella) macrior n. sp	Maq. of Minn.
Orthis petrae n. sp. (Dinorthis proavita)	Rich.
Orthis (Dinorthis) subquadrata Hall	Rich.
Rhynchonella (Rhynchotrema) capax Conrad	Rich.
Streptorhychus (Strophomena) trilobatum Owen	Tr.
Streptorhynchus (Strophomena) wisconsinensis Whitfield	Maq. of Wis.
Strophomena tenuistriata Sowerby (Leptaena richmondensis)	Rich.
Bellerophon bilobatus Sowerby (Sinuites cancellatus)	Tr.- Rich.
Murchisonia (Hormotoma) major Hall	Tr.
Murchisonia milleri Hall (Lophospira bicincta)	St. R.-Rich.
Cypricardites luculentus n. sp. (Cyrtodonta grandis luculenta)	Maq. of Minn.
Modiolopsis modiolaris Hall	Cin.
Pterinea demissa Hall	Mays.-Rich.
Tellinomya lepida n. sp. (Ctenodonta similis)	Rich.
Strophomena (Leptaena) unicostata M. and W	Rich.

This fauna is so characteristic of the Maquoketa in Minnesota and adjacent regions that there can be little doubt that the Wykoff beds belong to the Richmond. This indicates decidedly changed paleogeographic conditions as contrasted with the earlier Ordovician. In lower and middle Ordovician time, the clastics seem to have been derived from the northwest, in the central Mississippi valley region; whereas in Richmond time, limestone increases to the northwest, and sandstone (Thebes) to the south (pp. 37, 97).

WISCONSIN.

Oneota.

The oldest formation in Wisconsin to be assigned to the Ordovician is the Oneota. It is the lower or "Main" limestone of the Prairie du Chien or "Lower Magnesian" group. One of the best and most recently published descriptions is by Twenhofel and Thwaites.[172] As described by them it consists of moderately well-bedded gray to drab dolomite, very cherty, with a sparing development of sandstone layers near the base. The maximum thickness given by them is about 170 feet. Cyrptozoa are abundant, and a few cephalopods and low-spired gastropods are reported. No faunal list is given. The formation is correlated, on the basis of stratigraphic position, with the Gasconade of Missouri and the Oneota of adjacent states.

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[171] Minn. Acad. Sci., Bull. 3, pp. 319-343.
Bull. Geol. Soc. America, vol. 3, pp. 366-367; also American Geologist, vol. 18, 1896 and vol. 19, 1897.

New Richmond.

Within the Prairie du Chien group there occurs a thin sandstone, which was first called the New Richmond in Wisconsin, but which has a more extensive development in Iowa and Minnesota. The term has not been extensively employed in Wisconsin, in part because the sandstone member seems to be thin and discontinuous, but also in part because erosion has, at least locally, removed both Shakopee and New Richmond, before the St. Peter was laid down. Sufficiently detailed work has not been done to determine how important a factor the removal of the formation may be, over the state as a whole, but at least two recent papers (see p. 112) report the St. Peter resting directly on Oneota. Grant[173] reports a measured section of the Prairie du Chien which is as follows:

4.	Sandstone; St. Peter	70
3.	Sandstone and dolomite interbedded	40
2.	Sandstone	60
1.	Dolomite, thin greenish and black shales	104

Number 3 is probably Shakopee, number 2 New Richmond, and number 1 Oneota. The New Richmond is continuous with that formation in adjacent states, and is correlated with the Roubidoux of the Ozark region.

Shakopee.

This is the uppermost division of the Prairie du Chien group in the state. In few of the older reports, are the details of that group well enough differentiated so that they can be recognized in the descriptons. So far as they can be separated, the upper part of the group, corresponding probably to the Shakopee, seems to consist of somewhat more thinly-bedded, less crystalline dolomites than the Oneota below, and to contain more sandy and shaly layers interbedded. Chert is abundant, and *Cryptozoon minnesotense* is characteristic. A small fauna, described from the upper one-third of the Prairie du Chien is quite probably from the Shakopee.[174]

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[172] Twenhofel, W. H., and Thwaites, F. T., The Paleozoic section of the Tomah and Sparta quadrangles, Wisconsin; Jour. Geol. vol. 27, 1919, pp. 614-633.

[173] Grant, U. S., Report on the lead and zinc deposits of Wisconsin; Wis. Geol. and Nat. Hist. Survey, Bull. No. XIV, 1906, p. 28.

Shakopee fauna.

Helicotoma pecatonica Sardeson.
Raphistoma multivolvatum Calvin.
Raphistoma minnesotense (Owen) Sardeson.
Straparollus claytonensis Calvin.
Murchisonia argylensis Sardeson.
Subulites exactus Sardeson.
Crytoceras luthei Calvin.

Other forms are listed from the Prairie du Chien (Lower Magnesian) but since their exact horizons are not known, they are of less value.[175]

Prairie du Chien fauna.

Fucoids, gen. and sp.
Stromatopora concentrica, Goldf.
Leptaena barabuensis, Winchell.
Metoptoma barabuensis, Whitf.
Metoptoma recurva, Whitf.
Metoptoma retrorsa, Whitf
Metoptoma similis, Whitf.
Euomphalus strongi, Whitf.
Straparollus sp. undet.
Ophileta uniangularis, Vanuxem.
Ophileta sp.
Holopea (Pleurotomaria) turgida, Hall.
Holopea sp.?
Scaevogyra elongata, Whitf.
Scaevogyra obliqua, Whitf.
Scaevogyra swezeyi, Whift.
Orthoceras primigenium, Hall.
Dikellacephalus barabuensis, Whitf.
Dikellacephalus eatoni, Whitf.
Illaenurus covexus, Whitf.

The Shakopee of Wisconsin is correlated with that formation in adjacent states, and is presumed to be the equivalent of the Jefferson City and Cotter of Missouri and Arkansas (p. 39).

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[174] Grant, U. S., and Burchard, E. F., Lancaster-Mineral Point quadrangle, U. S. Geol. Survey, Folio 145, 1907.

[175] Whitfield, R. P., Geology of Wisconsin, vol. 1, 1873-79, pp. 362-375.

St. Peter.

In Wisconsin, this formation occurs as a U-shaped band with its base across the southern half of the state and its uprights on either side. On the east it is practically continuous to within 4 miles of the Michigan line, where it passes beneath drift, and is lost. On the west it is more dissected and less continuous, but extends in a ragged band as far north as the St. Croix river.

The St. Peter rests with marked unconformity on the Prairie du Chien. The most striking proof of this relationship, and the one most frequently cited, is the irregularity of the contact between the two. The greatest reported thickness of the sandstone is 212 feet, whereas, in places, owing to the unequal erosion, the Prairie du Chien rises into contact with the overlying Platteville[176]; and differences of elevation of the contact vary 100 feet within a quarter of a mile.[177]

Chamberlin noted conglomerate at the base of the formation[178] and observations in northwestern Wisconsin by Wooster[179] show brecciated chert and kaolin masses at the contact, which, in the light of our later studies, would certainly be interpreted as basal conglomerate and residual soil. More recent papers present conclusive evidence of the magnitude of this unconformity. Ulrich[180], in commenting on certain well records in the vicinity of Chicago, says:

> "Finely laminated, hard, silicious rock (would not like to call it shale) occurs in places in southeastern Wisconsin between the typical St. Peter and the Shakopee. Sometimes it includes, or is associated with, heavy chert conglomerate; and frequently there are red streaks or beds with the white. I regard these local deposits as erosion products, accumulated when the first Ordovician sea (the St. Peter) invaded this area. At one of these occurrences in Wisconsin I found these silicious deposits transgressing the bevelled edges of the Shakopee and finally resting on beds well down in the Oneota."

Twenhofel and Thwaites[181] have presented even more striking evidence of the importance of this break. They find at the contact an entirely structureless residual soil of clay and chert particles. Moreover, the St. Peter should normally rest upon the Shakopee, but that formation, if it was ever deposited in the Sparta region, is completely removed, together with the New Richmond, and the St. Peter erosion, at least locally, has cut through into the Jordan, on which the St. Peter is seen to rest in one locality. The erosion surface is reported to have a stratigraphic relief of at least 200 feet. Bain[182] also attributes the absence of the New Richmond and Shakopee over portions of the lead and zinc region of southwestern Wisconsin to pre-St. Peter erosion.

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[176] Chamberlin, T. C., Geology of Wisconsin, vol. 1, 1873-1879, p. 146.

[177] Chamberlin, T. C., Geology of Wisconsin, vol. 2, 1873-1877, pp. 277-285.

[178] Chamberlin, Geology of Wisconsin, vol. 2, p. 287.

[179] Geology of Wisconsin, vol. 4, 1873-79, p. 129.

[180] Ill. Geol. Survey, Bull. No. 34, 1919, p. 109.

[181] Jour. Geol., vol. 27, 1919, p. 632.

Chamberlin[183] describes certain elliptical mounds in the Prairie du Chien, at the base of the St. Peter, which give locally an appearance of discordance or angular unconformity between the two formations. From the descriptions they appear to be similar to structures already referred to from Minnesota (p. 98) which Sardeson has described as reefs of some sort. They vary in height to a maximum of 100 feet and in length to a maximum of about one-fourth of a mile, with slopes rarely exceeding 30°. They are quaquaversal, and the fact that their surfaces are seen to be eroded beneath the St. Peter shows that they were formed before the pre-St. Peter erosion interval. Chamberlin ascribes them to inequalities of deposition, and not to pre-St. Peter deformation. It is quite probable that they represent algal or stromatoporoid reefs.

Nothing else resembling pre-St. Peter folding or folding during St. Peter deposition, is reported, except the single instance cited by Sardeson[184] in southern Wisconsin, and this appears to be more probably simple settling due to solution in the underlying limestone. Sardeson's statement that Chamberlain

> "Wrote later correcting the theory that the great inequalities at the top of the 'Magnesian' was due to erosion and showing that the undulating surface was really due to folding of the upper part of the "Magnesian"

is hardly a fair statement of Chamberlin's views. Sardeson's authority for this statement is reported to be Geology of Wisconsin, Vol. I. To show that Chamberlin, however, does *not* ascribe these domes to actual folding, the following is quoted from pp. 139-140 of that reference:

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[182] Bain, H. F., Zinc and lead deposits of the Upper Mississippi Valley; Bull. U. S. Geol. Survey, No. 294, 1906, p. 18.

[183] Geology of Wisconsin, vol. 2, p. 226.

[184] Minn. Acad. Sci., vol. 3, pp. 81 and 86.

> "If we interpret these facts aright (the domes), they indicate a somewhat peculiar history for a limestone formation. We conceive that in the earlier stages of the period the limestone accumulated to considerable thickness, after which the depositing waters retired, leaving the surface exposed to drainage erosion, whereby it was carved, in some measure, into the usual irregularities of corroded surfaces. After this had taken place, the sea advanced, eroding still further and breaking up and grinding the superficial beds, heaping the broken and comminated material into shoals, bars and reefs.
>
> "As the sea advanced, these accumulations became more deeply covered with water so as to be at length beyond the forcible action of the waves, and they then became covered with a deposit of calcareous detritus, borne backward from the still advancing beach. This calcareous deposit covered the irregularities of the bottom like an undulatory blanket, forming the homogeneous, superficial layers above described. The effect of this last deposit would be to subdue the roughness and irregularities left by beach action, and give the prominences the flowing, billowy contour which they are observed to possess."

This quotation is given, not to demonstrate the origin of the domes, which the writer suspects are more probably organic reefs, but to show that Chamberlin did not, in the reference cited by Sardeson, ascribe them to true deformation, or retract his former statement of erosion between the "Magnesian" and St. Peter. In fact, on p. 145, the very page to which Sardeson refers for his authority, Chamberlin still expresses his belief in the eroded nature of this contact, by saying

> "Reposing upon the billowy surface of the Lower Magnesian limestone, filling up its depressions, and, for the most part surmounting its prominences, lies a singularly pure quartzose sandstone. Next the underlying limestone, to be sure, there is found some *shaly material derived from its wear.*"

(Italics are the present author's). No statement of erosion between the formations could be more specific.

Ripple marks, which are rare in the formation, are described from a single locality as being very "regular, parallel, and well-defined".[185] From the descriptions, it is not possible to say with certainty whether they are of the current or oscillation type, but they are more probably the latter.

Bedding is variously described as "well developed," "poorly developed", "regular", "irregular", and massive", so that little can be told of its character from the descriptions. The formation, however, would not appear to be so consistently well-bedded as in Illinois, Minnesota, and Missouri. The descriptions show that cross-bedding is not uncommon. Of it, however, Strong says[186]

> "The peculiarity of cross-stratification of the subordinate layers, already described as occurring in the Potsdam, is occasionally seen in the St. Peter; it is not, however, such a characteristic feature."

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[185] Strong, Moses, Geology of Wisconsin, vol. 2, 1873-77, p. 677.

[186] Strong, Moses, Geology of Wisconsin, vol. 2, p. 82.

This is in line with observations elsewhere to the effect that the St. Peter is less cross-bedded than most other sandstones.

The formation is said to become more shaly as traced northeastward.[187]

Size of grain is variously described as coarse, medium, and fine. All authors agree, however, as to the well-rounded character of the grains and the high degree of purity of the sand. Quartz enlargement is rather generally reported.

Fossils are very rare in the St. Peter of Wisconsin. Scolithus tubes are reported by Chamberlin[188] from the top of the sandstone, and also from beds more doubtfully referred to its base. Markings interpreted as fucoidal impressions also occur near the top. Sardeson[189] reports *Modiolopsis postica* and other species from the top of the St. Peter near Dodgeville.

Platteville.

There is no physical evidence of a break between the Platteville and St. Peter. The presence of the intervening Joachim, farther south (pp. 26-28, 43-44) has been taken to suggest an unconformity at this horizon. Further consideration of this subject is deferred to a later section (p. 219).

As most recently delimited,[190] the formation where carefully studied in the lead and zinc region averages 55 feet in thickness, with a minimum of 40 feet and a maximum of 65 feet. In the older reports, the boundaries of the formation have not always been placed at the same horizon, and hence some confusion arises as to interpretation. The Platteville consists essentially of buff to bluish thin-bedded limestone, becoming shaly toward the top. The uppermost shale beds probably represent in part the horizon of the Decorah as developed in Iowa and Minnesota. The formation is highly fossiliferous.

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[187] Chamberlin, Geology of Wisconsin, vol. 2, p. 287.

[188] Geology of Wisconsin, vol. 1, p. 147.

[189] Minn. Acad. Sci., Bull. 3, pp. 68-79.

[190] Folio 145, also Bull. U. S. Geol. Survey No. 294.

Fauna of the Platteville.

	Range.
*Streptelasma profundum	Bl. R.
Rafinesquina minnesotense	Bl. R.
*Orthis (Dinorthis) deflecta	St. R.-Bl. R.
*Orthis (Pianodema) subaequata	St. R.-Bl. R.
Protowarthia (Sinuites) rectangularis	Bl. R.
*Leperditia fabulites	St. R.-Bl. R.
Thaleops ovatus	Bl. R.
Maclurea (Maclurites) bigsbyi	Bl. R.
Zygospira nicolleti	Bl. R.
Hindia inequalis	Bl. R.
Rhinidictya pediculata	Bl. R.
Phylloperina (Chasmatopora) sublaxa	Chazy-Bl. R.
Monotrypa magna	Bl. R.
Rhynchotrema minnesotensis	Bl. R.
Ambonychia planistriata	Bl. R.
Clionychia lamellosa	Bl. R.
Salpingostoma buelli	Bl. R.
Conradella (Phragmolites) triangularis	Bl. R.
Hyolithes baconi	Bl. R.
Encrinurus vannulus	Bl. R.

The upper shale layers contain a large, broad variety of *Orthis* (*Pianodema*) *subaequata*, and two bryozoa, *Sticotporella frondifera* and *S. angularis*, elsewhere characteristic of the Decorah. Faunal lists in the older reports are subject to interpretation. The "Trenton" of Wisconsin, as of Iowa, included not only the Platteville, but also the Decorah and much of the less crystalline lower part of the Galena, as these formations are now delimited. Old lists of "Trenton" fossils are therefore commonly of but little importance in close correlation. One such list, however, separates the forms found in the "Lower Buff", "Lower Blue", "Upper Buff", and "Upper Blue". As near as can be told from careful comparison of older and more recent published descriptions, the first two, the "Lower Buff" and "Lower Blue," are very nearly the equivalents of the present Platteville, including the Decorah. In fact in the report on the "Geology and topography of the Lead Region", Strong* restricts the term "Trenton" to these two horizons. Also the average thickness of the Platteville is about equal to the average thickness of the "Lower Buff" and "Lower Blue" taken together, which further confirms the belief that these two make up the present Platteville. Chamberlin's[191] list from these two horizons is therefore appended, as the best available.

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*Geology of Wisconsin, vol. 2, p. 680.

[191] Geology of Wisconsin, vol. 2, 1873-77, pp. 320-326.

Fauna of "Lower Buff" and "Lower Blue," Platteville.

	Range.
Palaeophycus gracile (1)	?
Buthotrepis succulens (1-2)	Tr.
Schizocrinus nodosus (2)	Tr.
Stictopora elegantula (2)	Tr.
Lingula cf. obtusa (1)	Tr.
Orthis disparilis (ignicula) (1)	Chazy.
*Orthis perverta (1-2) (Pianodema subaequata perverta)	Bl. R.
Orthis (Dinorthis) subquadrata (1)	Rich.
Orthis (Dalmanella) testudinaria (2)	Bl. R.-Rich.
*Orthis tricenaria (1-2)	St. R.-Rich.
*Streptorhynchus deflectum (1-2) (Dinorthis deflecta)	St. R.-Bl. R.
Streptorhynchus deltoidum? (1) (Rafinesquina deltoidea)	Tr.
*Streptorhynchus filitextum? (1) (Strophomena incurvata)	St. R.-Bl. R.
Streptorhynchus (Strophomena) planumbonum? (1)	Rich.
Strophomena (Rafinesquina) alternata (1-2)	Tr.-Rich.
Strophomena camerata (1) (Rafinesquina deltoidea)	Tr.
Strophemena camura (1)	?
Strophomena incrassata (1) (Rafinesquina minnesotense)	Bl. R.
Ambonychia (Clionychia) lamellosa (2)	Bl. R.
Tellinomya iphigenia (2)	Rich.
*Tellinomya (Ctenodonta) nasuta (1-2)	Bl. R.-Tr.
*Tellinomya ventricosa (Ctenodonta gibberula) (2)	St. R.-Bl. R.
*Cypricardites (Cyrtodonta) canadensis (1)	Bl. R.
Cypricardites (Vanuxemia) niota (2)	Bl. R.
Cypricardites rectirostris (1)	Bl. R.
Cypricardites (Vanuxemia) rotundatus (1-2)	Bl. R.
Cypricardites subtruncatus? (1)	?
Cypricardites ventricosus (Cyrtodonta billingsi) (1-2)	Bl. R.
Modiolopsis (Whiteavesia) superba (1)	Bl. R.
*Raphistoma lenticularis (Liospira vitruvia) (1-2)	Bl. R.-Rich.
Raphistoma nasoni (Eotomaria supracingulata) (2)	Bl. R.
*Helicotoma planulata (1-2)	Bl. R.
Trochonema (Pleurotomaria) ambiguum (1-2)	Tr.
Trochonema umbilicatum (1-2)	Bl. R.-Tr.
*Pleurotomaria (Clathrospira) subconica (1-2)	Bl. R.-Rich.
*Murchisonia (Lophospira) bicincta? (1)	St. R.-Rich.
*Murchisonia (Hormotoma) gracilis (2)	Tr.-Rich.
*Murchisonia helicteres (2) (Lophospira serrulata)	Bl. R.
Murchisonia pagoda (Eotomaria prisca) (2)	Bl. R.
Murchisonia (Lophospira) tricarinata (1-2)	Bl. R.
Holopea obliqua (1)	St. P. ?-Tr.
Subulites elongatus (1-2)	Tr.
Calisospira occidentalis (2)	?
Maclurea (Maclurites) bigsbyi (2)	Bl. R.
Metoptoma (Archinacella) perovalis (2)	Bl. R.
Bucania (Tetranota) bidorsata (1-2)	St. R.-Tr.
Bucania (Salpingostoma) buelli (2)	Bl. R.
Bellerophon (Tetranota) wisconsinensis (1-2)	Bl. R.
Hyolithes baconi (2)	Bl. R.
*Pterotheca attenuata (1-2)	Bl. R.
Orthoceras (Spyroceras) anellum (1-2)	Bl. R.-Tr.
Orthoceras junceum (1-2)	Bl. R.-Tr.
Orthoceras (Tripteroceras) planoconvexa (1-2)	Bl. R.-Tr.
Orthoceras vertebrale (Cycloceras olorus) (1-2)	Bl. R.-Tr.
Orthoceras (Actinoceras) beloitense (1-2)	Bl. R.
*Endoceras proteiforme (2)	Bl. R.-Rich.
Cyrtoceras corniculum (tenuistriatum) (2)	Bl. R.

	Range.
Cyrtoceras eugium (2)	Bl. R.
Oncoceras lycus (2)	Bl. R.
Oncoceras pandion (1-2)	Bl. R.
Oncoceras plebeium (1-2)	Bl. R.
Gyroceras convolvans (Barrandeoceras americanum?)	Bl. R.
Gonioceras anceps (2)	Bl. R.
Lituites occidentalis (1)	?
*Leperditia fabulities (1-2)	St. R.-Bl. R.
Illaenus (Thaleops) ovatus (2)	Bl. R.-Rich.
Illaenus taurus (americanus) (1)	Tr.
*Asaphus (Basilicus) barrandi (2)	Bl. R.
Asaphus (Isotelus) iowensis (2)	Rich.
Ceraurus pleurexanthemus (1-2)	Bl. R.-Tr.

Forms in the above list marked (1) are from the "Lower Buff" beds, those marked (2) are from the "Lower Blue." As in the other examples of the Platteville fauna studied, the list is characteristic of the formation in adjacent states, and is strongly Black River in its general affinities. According to Bassler's "Index," eighteen of the forms, those marked with a star, are found in the Lowville or in beds definitely correlated with that formation. Even the starred forms, however, do not constitute a characteristic Lowville assemblage. As already pointed out (p. 103) the equivalent of the Lowville is probably present in the Platteville, but the faunal evidence is by no means satisfactory on this point.

Decorah.

The Decorah has much less important development in Wisconsin than in Iowa and Minnesota, and is not recognized as a distinct and separate formation in the geological survey reports of the state. In general, the lithologic descriptions are not sufficiently detailed to enable one to determine with any degree of certainty the extent or thickness of that horizon. In the Lancaster-Mineral Point Folio (No. 145) a thin blue shale is described at the top of the Platteville, which is characterized by an abundance of *Stictoporella frondifera and S. angularis*, both typical Decorah forms. A most careful study of the older reports would seem to show no recognized horizon corresponding to the Decorah. In fact, that horizon is quite probably included in the "Lower Blue," of the earlier geologists. The "Upper Buff" and "Upper Blue" are much more probably Galena, though the "Upper Buff" may in places include Decorah,

Galena.

This formation rests on the Platteville (or Decorah) without visible evidence of any break, although Grant and Burchard[192] believe the relations are unconformable, and Bain[193] is inclined to accept the same conclusion. For the most part, the Galena consists of rather massive coarsely crystalline somewhat cherty dolomite, with occasional thin-bedded more shaly members, and averages between 200 and 250 feet thick in the lead and zinc district, where it has been best studied.

A careful reading of later and older reports leads to the conclusion that to the Galena of earlier authors must be added the "Upper Buff" and "Upper Blue" beds of the so-called "Trenton," to produce the equivalent of the Galena as the term is now used. This conclusion is strengthened by a comparison of thicknesses. If to the average thickness of the Galena as described by Chamberlin,[194] about 160 feet, be added his figures for the average of the "Upper Buff," 55 feet, and the "Upper Blue," 15 feet, the total is 230 feet, which is about the average assigned to the Galena as delimited at present.

A small fauna from the base of the Galena is listed in Folio 145, and is appended herewith.

Galena fauna, Folio 145.

	Range.
Orthis tricenaria	**St. R.-Bl. R.**
Orthis (Dinorthis) pectinella	**Bl. R.-Tr.**
Orthis (Dalmanella) testudinaria	**Bl. R.-Rich.**
Plectambonites sericeus	**Bl. R.-Rich.**
Leptaena charlottae	**Bl. R.**
Rafinesquina alternata var	**Tr.-Rich.**
Strophomena incurvata var	**St. R.-Bl. R.**
Ctenodonta astartaeformis	**Bl. R.**
Vanuxemia niota	**Bl. R.**
Ceraurus pleurexanthemus	**Bl. R.-Tr.**
Receptaculites oweni	**Bl. R.-Tr.**
Lingula sp	

This assemblage is more closely related to the Platteville and Decorah of other regions than to typical Galena, and suggests that the basal Galena, as that formation is now defined, is probably Black River.

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[192] Folio 145.

[193] Bull. U. S. Geol. Survey, No. 294, p. 24.

[194] Geology of Wisconsin, vol. 2, p. 307, and p. 291.

The following fauna is reported from a single quarry in the upper two-thirds of the "Upper Buff" beds.[195]

Fauna of the "Upper Buff" beds.

	Range.
Buthotrephis succulens	Tr.
Streptelasma corniculum	Tr.
Chaetetes lycoperdon	?
Chaetetes discoideus	?
Stictopora elegantula	Tr.
Stictopora n. sp.	
Schizocrinus nodosus	Tr.
Ptilodictya (Escharopora) recta	Tr.
Lingula sp. undet.	
Orthis perverta (Pianodema subaequata perverta)	Bl. R.
Orthis (Plectorthis) plicatella	Mays.
Orthis (Dalmanella) testudinaria	Bl.-Rich.
Orthis (Dinorthis) pectinella	Bl. R.-Tr.
Orthis tricenaria	St. R.-Bl. R.
Orthis (Hebertella) bellarugosa	Chazy-Bl. R.
Strophomena camerata (Rafinesquina deltoidea)	Tr.
Strophomena (Rafinesquina) alternata	Tr.-Rich.
Stropheodonta sp. undet.	
Streptorhynchus (Dinorthis) deflecta	St. R.-Bl. R.
Streptorhynchus subtentum (Strophomena planumbona)	Rich.
Leptaena (Plectambonites) sericea	Bl. R.-Rich.
Ambonychia (Clionychia) lamellosa	Bl. R.
Cypricardites (Vanuxemia) niota	Bl. R.
Cypricardites (Vanuxemia) rotundatus	Bl. R.
Cypricardites ventricosus	Bl. R.
Tellinomya (Ctenodonta) nasuta	Bl. R.-Tr.
Tellinomya (Ctenodonta) alta	Tr.
Tellinomya iphigenia	Rich.
Tellinomya (Ctenodonta) levata	Tr.
Tellinomya ventricosa (Ctenodonta gibberula)	St. R.-Bl. R.
Modiolopsis (Whiteavesia) superba	Bl. R.
Modiolopsis (Eurymya) plana	Bl. R.
Raphistoma lenticularis (Liospira vitruvia)	Bl. R.-Rich.
Raphistoma nasoni (Eotomaria supracingulata)	Bl. R.
Trochonema (Pleurotomaria) ambiguum	Tr.
Trochonema umbilicatum	Bl. R.-Tr.
Trochonema beloitense	Bl. R.
Pleurotomaria (Clathrospira) subconica	Bl. R.-Rich.
Murchisonia (Lophospira) bicincta	St. R.-Rich.
Murchisonia (Hormotoma) gracilis	Tr.-Rich.
Murchisonia helicteres (Lophospira serrulata)	Bl. R.
Murchisonia pagoda (Eotomaria prisca)	Bl. R.
Murchisonia (Lophospira) tricarinata	Bl. R.
Cyclonema (Gyronema) percarinatum	Tr.
Subulites elongatus	Tr.
Clisospira occidentalis	?
Helicotoma planulata	Bl. R.
Maclurea (Maclurites) bigsbyi	Bl. R.
Metoptoma (Archinacella) perovalis	Bl. R.
Bellerophon bilobatus (Sinuites cancellatus)	Tr.-Rich.
Bellerophon (Tetranota) wisconsinensis	Bl. R.

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[195] Geology of Wisconsin, vol. 2, pp. 299-300.

	Range.
Bucania (Salpingostoma) buelli	Bl. R.
Bucania punctifrons	Tr.
Bucania (Tetranota) bidorsata	St. R.-Tr.
Pterotheca attenuata	Bl. R.
Hyolithes baconi	Bl. R.
Cyrtoceras annulatum (Spyroceras subannulatum)	Tr.
Cyrtoceras corniculum (tenuistriatum)	Bl. R.
Cyrtoceras eugium	Bl. R.
Cyrtoceras (Maelonoceras) neleus	Bl. R.-Tr.
Oncoceras abruptum	Bl. R.
Oncoceras alceus	Bl. R.
Oncoceras lycus	Bl. R.
Oncoceras pandion	Bl. R.
Oncoceras plebeium	Bl. R.
Orthoceras (Spyroceras) anellum	Bl. R.-Tr.
Orthoceras multicameratum	Bl. R.
Orthoceras junceum	Bl. R.-Tr.
Orthoceras (Tripteroceras) planoconvexum	Bl. R.-Tr.
Orthoceras (Actinoceras) beloitense	Bl. R.
Orthoceras vertebrale (Cycloceras olorus)	Bl. R.-Tr.
Endoceras annulatum	Tr.
Endoceras proteiforme	Bl. R.-Rich.
Gonioceras anceps	Bl. R.
Illaenus (Thaleops) ovatus	Bl. R.-Rich.
Asaphus (Isotelus) iowensis	Rich.
Ceraurus pleurexanthemus	Bl. R.-Tr.
Leperditia fabulites	St. R.-Bl. R.

This fauna of 78 species came from the upper 37 feet of the 55 foot "Upper Buff" limestone, within what must certainly be considered the lower part of the Galena as that formation is now expanded. Of the 78 species, 34 are not found elsewhere higher than Decorah or Platteville, and are listed in Bassler's "Index" as Black River or earlier. Twenty-one of the species are not found in the typical Platteville or Decorah, and are listed as Trenton or later in the "Index", four of them being restricted elsewhere, to the Cincinnatian. This would surely indicate strongly that the basal Galena is Black River, a conclusion suggested by the analysis of certain Illinois faunas (p. 90). This is still further suggested by a study of the fauna given below from the 15 foot "Upper Blue" bed, from which 18 species are listed.[196] Of these, 10 are not listed above the Platteville and Decorah in Bassler's "Index", which gives them as Black River and earlier; while only one is supposed to be restricted to the Galena or higher horizons, in other areas. This fauna, like that of the "Upper Buff" beds, is a characteristic Platteville-

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[196] Geology of Wisconsin, vol. 2, 320-326.

Decorah assemblage. A comparison of thicknesses, however, shows the following condition.

"Upper Blue"	15 feet
"Upper Buff"	55 feet
"Lower Blue"	25 feet
"Lower Buff"	25 feet
Total	120 feet

This is much in excess of any thickness now assigned to the Platteville-Decorah section in Wisconsin, and it is clear that these basal Black River beds are included in the Galena at the present time.

Fauna of the "Upper Blue."

	Range.
Orthis (Hebertella) bellarugosa	Chazy-Bl. R.
Orthis (Platystrophia) lynx	Bl. R.-Rich.
Orthis (Dinorthis) pectinella	Bl. R.-Tr.
Orthis perverta (Pianodema subaequata perverta)	Bl. R.
Orthis (Plectorthis) plicatella	Mays.
Orthis (Dalmanella) testudinaria	Bl. R.-Rich.
Orthis tricenaria	St. R.-Bl. R.
Strophomena (Rafinesquina) alternata	Tr.-Rich.
Leptaena (Plectambonites) sericea	Tr.-Rich.
Tellinomya ventricosa (Ctenodonta gibberula)	St. R.-Bl. R.
Cypricardites (Vanuxemia) niota	Bl. R.
Cypricardites (Vanuxemia) rotundatus	Bl. R.
Cypricardites ventricosus	Bl. R.
Modiolopsis (Whiteavesia) superba	Bl. R.
Raphistoma lenticularis (Liospira vitruvia)	Bl. R.-Rich.
Bucania (Salpingostoma) buelli	Bl. R.
Bellerophon (Tetranota) wisconsinensis	Bl. R.
Ceraurus pleurexanthemus	Bl. R.-Tr.

Faunas are also described in the older reports from the Galena proper, that is from the crystalline dolomite above the "Upper Blue" and below the Maquoketa.[197]

Galena fauna.

	Range.
Receptaculites globularis (Ischadites iowensis)	Tr.
Receptaculites oweni	Bl. R.-Tr.
Climacograptus typicalis	Tr.
Lingula quadrata (iowensis)	Tr.
Orthis (Plectorthis) equivalvis	Mays.
Orthis (Platystrophia) lynx	Bl. R.-Rich.
Orthis perverta (Pianodema subaequata perverta)	Bl. R.
Orthis (Dalmanella) testudinaria	Bl. R.-Rich.
Orthis tricenaria	St. R.-Bl. R.
Streptorhynchus deltoideum (Rafinesquina deltoidea)	Tr.-Rich.
Strophomena (Rafinesquina) alternata	Tr.-Rich.
Leptaena (Plectambonites) sericea	Bl. R.-Rich.

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[197] Geology of Wisconsin, vol. 2, pp. 320-326.

	Range.
Atrypa (Cyclospira) bisulcata	Tr.
Rhynchonella (Rhynchotrema) anticostiense	Rich.
Rhynchotrema capax	Rich.
Ambonychia (Clionychia) erecta	Bl. R.
Ambonychia (Clionychia) lamellosa	Bl. R.
Ambonychia (Byssonychia) radiata	Mays.-Rich.
Cypricardites (Vanuxemia) rotundatus	Bl. R.
Cypricardites (Whitella) subtruncatus	Tr.
Cypricardites ventricosus	Bl. R.
Raphistoma lenticularis (Liospira vitruvia)	Bl. R.-Rich.
Trochonema umbilicatum	Bl. R.-Tr.
Murchisonia (Lophospira) bicincta	St. R.-Rich.
Murchisonia (Hormotoma) major	Tr.
Holopea paludiniformis	Tr.
Fusispira elongata	Tr.
Fusispira ventricosa	Tr.
Maclurea (Maclurina) subrotunda	Tr.
Conularia trentonensis	Tr.
Orthoceras amplicameratum	Tr.
Orthoceras junceum	Bl. R.-Tr.
Orthoceras (Tripteroceras) planoconvexa	Bl. R.-Tr.
Oncoceras plebeium	Bl. R.

Of 34 forms listed in this fauna, only 7 are recorded by Bassler as limited to the Black River or lower horizons, and 12 are limited to the Trenton, while 12 others are reported in the Trenton, and other beds. This is a much more characteristic Galena assemblage than the preceding. If the Galena is to be defined as all the beds between the Decorah shaly horizon below and the Maquoketa shales above, then it seems quite certain that it ranges from Black River into Trenton, an interpretation that is hardly in accord with statements that it is younger than the Kimmswick (p. 33).

Maquoketa.

This formation, known in the older reports as "Hudson River," or Cincinnatian rests on the Galena, and passes beneath the Silurian. It varies from about 150 to 250 feet in thickness, the variation probably due in part to Post-Galena and pre-Maquoketa erosion. A thin chert conglomerate is said to occur at the base.[198] Aside from this, little evidence of unconformity beyond the absence of the Eden-Maysville is reported from Wisconsin, but in Illinois and Missouri (pp. 36, 95) the evidence of such erosion seems to be conclusive.

Published sections show the Maquoketa to consist largely of very thin-bedded bluish to gray shale, with thin limestone beds locally developed. Shale makes up a very large proportion of the whole, and no beds are described that appear to be similar to the Wykoff of Minnesota. A considerable fauna is described from the formation.[199]

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[198] Folio 145.

Maquoketa fauna, lower 60 feet.

	Range.
Murchisonia (Hormotoma) gracilis	St. R.-Rich.
Coleolus iowensis	Rich.
Orthoceras sociale	Rich.
Calymene mammillatus	Rich.
Spatiopora iowensis	Rich.
Liospira micula	Tr.-Rich.
Leptobolis occidentalis	Rich.
Pleurotomaria depauperata	Rich.
Hoylithes parviusculus	Rich.
Clidophorus neglectus	Rich.
Ctenodonta fecunda	Rich.

Maquoketa fauna, near the top.

Monotrypella (Rhombotrypa) quadrata	Rich.
Monotrypa rectimuralis	Girardeau
Heterotrypa (Dekayella) singularis	Rich.
Plectambonites saxea	Rich.
Leptaena unicostata	Rich.
Plectorthis whitfieldi	Rich.
Dinorthis subquadrata	Rich.
Platystrophia acutilirata var	Rich.
Rhynchotrema capax	Rich.
Rhynchotrema perlamellosa	Rich.
Rhynchotrema neenah	Rich.

This fauna is highly typical of the Maquoketa throughout the upper Mississippi Valley, and is sufficient to correlate that horizon definitely with the Richmond.

INDIANA, OHIO AND KENTUCKY.

So little is really known of the St. Peter and Beekmantown of these states, and that little indicates such similar conditions throughout, that the three are grouped for descriptive purposes. Rocks older than the Trenton do not outcrop at all in the first two, and only in the extreme eastern part of the third. The information is gathered from deep well records; and churn drill cuttings, at best, are difficult to correlate. In Indiana, Phin-

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[199] Folio 145.

ney[200] reports St. Peter in several wells. It is the first dominantly sandy horizon below the Trenton. Phinney describes it as

> "Largely calcareous, only a small residue of silica and crystals of quartz remaining after digestion in acid. The term sandstone usually given to it is hardly the proper one, to use here, 'silicious limestone' better indicating its composition."

Locally, thin lenses of it are essentially pure sand, but of the maximum of 227 feet assigned to it, a very large proportion is chiefly limestone, with some shale.

Descriptions of the St. Peter from Ohio are rather conflicting. Orton[201] describes the formation as a more or less calcareous sandstone, 40 to 60 feet thick, reported in most of the deep wells of the state. Just across the river from Cincinnati, a deep well penetrated 65 feet of sandstone believed to represent the St. Peter. Analysis showed 67.15 per cent silica.

In the Waverly well Bassler[202] reports 175 feet of white saccharoidal sandstone, of which no further description is given. Stout[203] reports these beds, however, to contain considerable interstratified shale. Another report,[204] which describes this as the only sandy horizon in over 500 feet below the base of the Trenton, refers to 82 feet of light colored sand with a subordinate quantity of shale overlying 75 feet of gray sand with a larger proportion of shale.

Fuller[205] reports the St. Peter of Ohio to be a shaly calcareous sandstone, yielding saline sulphur water. The records of the few wells that penetrated the horizon show wide variations in thickness which apparently result from inability to recognize, in the cuttings, the precise boundaries of the formation.

Shaw[206] reports from Kentucky an unknown thickness of siliceous limestone or calcareous sandstone which he correlates with the St. Peter.

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[200] Phinney, A. J., The natural gas field of Indiana; Eleventh Ann. Rept. U. S. Geol. Survey, pt. I, 1893, pp. 625-636.

[201] Orton, Edw., Rept of the Geol. Survey of Ohio, vol. VI, 1888, pp. 7, 299.

[202] Bassler, R. S., The stratigraphy of a deep well at Waverly, Ohio; Am. Jour. Sci., 4th ser., vol. 31, 1911, pp. 19-24.

[203] Stout, Wilbur, Geology of southern Ohio; Ohio Geol. Survey, 4th ser., Bull. 20, pp. 666-667.

[204] Ohio Geol. Survey, 4th Ser., Bull. 12, p. 48.

[205] Fuller, M. L., and Clapp, F. G., The underground waters of southwestern Ohio; U. S. Geol. Survey, Water Supply Paper 259, 1912, pp. 23, 31, 48-49.

[206] Shaw, E. W., The Irvine Oil Field, Estill County, Kentucky; Bull. U. S. Geol. Survey, No. 661, 1918, pp. 152-155.

Matson[207] correlates a fine grained silicious limestone in Kentucky with the St. Peter of the Mississippi Valley region. The horizon yields sulpho-saline water. Similar sandstones are described by Butts,[208] who reports that they are at about the St. Peter horizon, but believes that they may not all be the same bed, but may include lower horizons within the Beekmantown.

The above data are far from being satisfactory, but they seem to indicate that the St. Peter, if it is present at all in this area, is probably very generally calcareous, grading into limestone, and this constitutes good evidence that the sands of the formation in the central Mississippi Valley were probably not derived from sources to the east.

MICHIGAN.

According to Smith[209], the "Calciferous" (the "Lower Magnesian" or Prairie du Chien) outcrops sparingly in the Upper Peninsula, where it is known as the Hermansville limestone. It consists of limestone with much interbedded white sandstone difficult to distinguish from the Potsdam below or the St. Peter above. Concerning the presence of the St. Peter, Smith says:

> "Exposures of the St. Peter sandstone are not known in Michigan. Apparently it is about 75 feet thick at Marinette (Wis.), absent near Stonington and 18 feet thick at Rapid River, but farther east in the Northern Peninsula it has not been recognized. The formation is very irregular in thickness and appears to fill hollows in the eroded surface of the Calciferous. In the southern Peninsula it has not been penetrated."

The "Trenton" also outcrops sparingly in the Upper Peninsula, but is not closely correlated with the Platteville, Decorah, and Galena. It is said to have a sandy middle division, which may correspond with the clastic Decorah.

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[207] Matson, G. C., Water resources of the Blue Grass Region, Kentucky; U. S. Geol. Survey, Water Supply Paper, No. 233, 1909, pp. 16-18, 92, 96, 103, etc.

[208] Butts, Chas., Geology and mineral resources of Jefferson County, Kentucky; Geol. Survey of Kentucky, ser. IV, vol. III, pt. 2, 1915, pp. 33-37.

[209] Smith, R. A., Occurrence of oil and gas in Michigan; Mich. Geol. and Biol. Survey, Pub. 14, 1914, p. 22.

KANSAS AND NEBRASKA.

Very little is actually known about the St. Peter in these two states. A few deep wells have penetrated sandstones at about the horizon where that formation should be encountered, and those sandstones have been correlated with the St. Peter, but in general, rather tentatively, however.

At Leavenworth, Kansas, a well 2116 feet deep penetrated gray sandstone at 1812 feet.[210] The Cambrian-Ordovician portion of the log is appended, as presented by Hinds and Greene.[211]

Portion of log of Leavenworth prospect well.

	Thickness in feet.	Depth in feet.
Ordovician system:		
Joachim (?) limestone		
Limestone, light gray	30	1710
St. Peter sandstone		
Sandstone, gray, hard	102	1812
Sandstone, "sharp," soft	18	1830
"Pebble sand rock," white	40	1870
Ordovician and Cambrian systems:		
"Rock" white, hard (limestone?)	50	1920
Sandstone, blue to white, soft	90	2010
Limestone	106	2116

A well near Yates Center, Woodson county, Kansas,[212] is reported to penetrate 50 feet of Chattanooga Black Shale, below which in descending order are 25 feet of limestone, 15 feet of sandstone doubtfully correlated with the St. Peter, 635 feet of unclassified limestone, 30 feet of mixed sandstone and limestone and granite believed to be pre-Cambrian. While there is no reason known why the sandstone may not be St. Peter, the presence of sandstone lenses in the Cotter and Jefferson City, as well as the occurrence of the Roubidoux, all of which are very similar lithogically to the St. Peter itself, renders very uncertain any correlation of a thin sandstone in so isolated an occurrence.

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[210] Jameson, E., Geology of the Leavenworth prospect well; Kan. Acad. Sci., Trans., vol. 11, 1889, pp. 37-38.

[211] Hinds, Henry, and Greene, F. C., U. S. Geol. Survey, Leavenworth-Smithville Folio, No. 206, 1917.

[212] Moore, R. C., Oil and gas resources of Kansas; Bull. Kan. Geol. Survey, No. 3, 1917, p. 143.

On page 218 of the same report, Moore gives the log of a deep well at Iola, Allen county, Kansas, part of which is quoted below.

Portion of log of Iola deep well.

Cambrian and Ordovician systems:		
Limestone	50	1318
Shalo, calcareous	22	1340
Sandstone	8	1348
Flint	12	1360
Dolomite, arenaceous, with flint	140	1500
Limestone, dolomitic, cherty	195	1695
Sandstone, dolomitic	29	1724
Dolomite, arenaceous	326	2050
Shale, dolomitic, arenaceous	30	2080
Sandstone, olive	25	2105
Sandstone	52	2157
Conglomerate	23	2180
Cambrian system, perhaps Algonkian in part.		
Sandstone, conglomerate (?)	823	3003

It is very difficult to correlate the beds in this record with the known sections. If the 8 feet of sandstone represents St. Peter, the 29 feet may well be the Roubidoux, and the 25 feet of olive sandstone with the 52 feet of sandstone below it might represent an abnormal development of the basal Gunter member of the Gasconade. It is quite as possible, however, that the St. Peter is not present, and that the 8-foot bed is a member of the Powell or Cotter, the other still being interpreted as Roubidoux and Gunter. So far as is known, not a particle of evidence exists to decide between these possibilities.

At Nebraska City[213], Nebraska, 64 feet of St. Peter is reported directly beneath the Decorah Shale, the Platteville being absent. Below the St. Peter there is reported to be 22 feet of red rock and shale, and below that more sandstone. The Decorah was identified by Ulrich, from fossil fragments, so that little doubt exists as to the correctness of the interpretation. The cause of the absence of the Platteville is by no means clear. The Decorah is reported to be about 29 feet thick, which is about normal. The lower sandstone may be Everton.

At Lincoln, Nebraska[214], a diamond-drill test well was put down by the state, to a depth of 2463 feet. Between 1947.6 feet and 2008 feet occurs 60.6 feet of dark gray siliceous sandstone, with coarse but uniform grains, that has been correlated with the St. Peter. Above it is a limestone low in magnesia, carrying fragments of crinoid stems, that has been assigned to the "Trenton." Next below the sandstone is 113 feet of sandy magnesian limestone which might be the Shakopee, though the author has made no effort to correlate it. Below that is 72 feet of soft red sandstone which might quite plausibly be correlated with the New Richmond, were it not for the fact that the rock below it is all quartzitic sandstone to the bottom of the well, 270 feet. The author suggests that this last may be the Sioux quartzite.

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[213] Norton, W. H., Underground water resources of Iowa; U. S. Geol. Survey, Water Supply Paper 293, 1912, pp. 74, 902-903.

[214] Sixth Bienn. Rept. Comm. Pub. Lands and Bldgs., Neb., 1888, pp. 59-84.

A seam of coal indicating clearly a Pennsylvanian horizon was reached at 942 feet, and the base of the Carboniferous was placed at 1080 feet. It is not clear whether this refers to the base of the Pennsylvanian, or the Mississippian. The base of the latter if it has its normal thickness should be considerably farther below the coal seam than this would indicate.

A study of wells in northwestern Iowa[215] seems to show that the Mississippian laps westward from Devonian across Silurian directly onto Ordovician. In Cherokee county, Iowa, the Mississippian is reported directly on the Galena, and similar conditions are probable in Ida county and Palo Alto county, Silurian and Devonian, if present at all, being very thin, and the Maquoketa entirely absent. This would suggest the possibility that farther west in Nebraska the Carboniferous might lap across onto still older formations, just as it does in the Ozark region, where Mississippian laps across from Devonian to Beekmantown, being then almost completely eroded at the Ozark crest, and the Pennsylvanian similarly overlapping onto the Beekmantown. In Minnesota and northwestern Iowa, as has already been shown (pp. 71, 101), there is an arching of the rocks that brings up the Sioux quartzite. About its borders, however, the Ordovician and probably also the Cambrian sediments seem to have about their normal development, as though they once overlapped the old basement, far beyond their present limits.

In the light of these facts, it seems highly plausible that the St. Peter was not encountered in the Lincoln test at all. If the lower 270 feet are actually Sioux quartzite, and the Cambrian and Beekmantown have their normal development, the sandstone therein called St. Peter might fall much nearer the Jordan, possibly with the Mississippian directly overlapping it.

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[215] U. S. Geol. Survey, Water Supply Paper 293,

Such an interpretation is not at all impossible, and accords well with the known facts concerning the "Nemaha Granite Range" of Kansas. According to the latest and best information available[216] this uplift extends with axis about N. 10 [illegible] from Chase county into Nemaha county, where it appears to reach its crest, and from which county it takes its name. Here the Pennsylvanian rests directly on the granite at a depth of 586 feet. There does not appear to be any longer the least doubt either that the granite mass exists, or that it is unconformable beneath the Pennsylvanian rather than intrusive into it. The writer is in essential accord with Moore's conclusion that the ridge does not represent an old pre-Cambrian monadnock, but is the eroded crest of a more recent uplift, probably more or less synchronous with the Ozark doming and not improbably with that of northwest Iowa and western Minnesota, already mentioned.

This ridge is said to pass northward into Pawnee county, Nebraska, and Lincoln would therefore be about on a line with its axis. The Carboniferous might, therefore, be expected to overlap onto early Ordivician or Cambrian sediments in this locality.

Nothing is known of possible or probable St. Peter west of this granite ridge in either Kansas or Nebraska.

COLORADO AND WYOMING.

In the Colorado Springs area[217] next above the Cambrian Sawatch sandstone is the Manitou limestone, with a maximum thickness of 250 feet. It varies from massive to thin-bedded, and from fine grained to coarsely crystalline. In the description given, there does not appear to be any shale or sandstone in the entire section, though the formation is said (Folio 198) to be slightly arenaceous at the base. Clearly it was laid down either far from a land mass, or else the adjacent land was so low as not to be yielding any sediment of consequence. Since this is correlated with the Beekmantown, it is particularly striking that sand is entirely absent, inasmuch as the Beekmantown sediments of the Mississippi Valley region are characteristically sandy. The sand of these sediments, then, would not appear to have been derived from the Colorado region. Reasons are given elsewhere for believing that the St. Peter sand probably came from the same source as the sand beds of the Beekmantown.

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[216] Taylor, Chas., The granites of Kansas; Bull. Southwestern Assoc. Petroleum Geologists, vol 1, 1917, pp. 111-126.
Powers, Sidney, Granite in Kansas; Am. Jour. Sci., vol. 44, 1917, pp. 146-150.
Moore, R. C., Oil and gas resources of Kansas; Kan. Geol. Survey, Bull. 3, 1917, pp. 140-173.

[217] U. S. Geol. Survey, Folio 203, 1916.

A small fauna has been collected from the Manitou, and is listed below:

Manitou fauna (Folio 203).

Lingulella desiderata.
Schizambon manitounesis.
Eoorthis desmopleura.
Eoorthis nympha.
Syntrophia nundina.

This is essentially a western fauna, and four of the five forms are also listed from the Cambrian, but are said to be characteristic of the Lower Ordovician in this and adjacent regions. In the Pikes Peak Folio[218] Cross refers to the occurrence of *Ophileta* and *Camarella* characteristic of the lower Silurian (Ordovician) in this limestone. While neither of these genera are strictly limited to the Beekmantown beds, they are highly characteristic. Richardson[219] also described a small fauna in the Castle Rock region.

Fauna from lower 25 feet of Manitou.

Billingsella plicatella.
Eoorthis desmopleura.
Owenella n. sp.
Cameroceras n. sp.
Eccyliomphalus sp.
Holopea or Hormotoma.
Fragments of trilobites.

Fauna from upper thin-bedded Manitou.

Hormotoma cf. H. gracilis.
Lophospira cf. gregaria (Billings).
Ophileta n. sp.
Acrotreta sp.

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[218] U. S. Geol. Survey, Folio 7, 1894.

[219] U. S. Geol. Survey, Folio 198, 1915.

Next above the Manitou is the Harding sandstone. Darton[220] reports that it is calcareous in the lower part, developing locally into fine-grained dolomite, and that it is shaly throughout. The maximum thickness is about 100 feet. According to Darton it rests with apparent conformity on the Manitou, but overlaps on the Cambrian sandstone and the pre-Cambrian gneiss. According to Cross[221], however, there is some evidence, at least locally, of erosion of the surface of the Manitou.

The Harding has been described in detail by Walcott.[222] In the area where Walcott collected the famous fish remains, the sandstone rests directly on the gneiss, and is overlain with apparent conformity by the Fremont limestone. The total thickness is 86 feet. There are persistent shale horizons, and the formation is thin-bedded. In addition to the fish remains, the formation has yielded the following invertebrate fauna.

Fauna of the Harding sandstone.

	Range.
Lingula, like L. attenuata Salter and L. belli Billings	Chaz.-Tr.
Modiolopsis, like M. trentonensis	Tr.
Modiolopsis, 3 sp. undet.	
Cypricardites, like C. ventricosa Hall	Bl. R.
Cypricardites (Vanuxemia) like C. rotundata Hall	Bl. R.
Cypricardites, 2 sp., undet.	
Orthonota, sp. undet.	
Tellinomya, 3 sp. undet.	
Helicotoma, sp. undet.	
Pleurotomaria, sp. undet.	
Murchisonia, sp. undet.	
Orthoceras multicameratum Hall	Bl. R.
Cyrtoceras, sp. undet.	
Leperditia, type of L. fabulites Conrad	St. R.-Bl. R.

This list, while by no means conclusive, surely shows close relationship to the Black River. The break, then, between the Beekmantown and overlying beds (the St. Peter break) appears to involve a greater hiatus here than in the Mississippi Valley region, the area seemingly receiving no deposits during St. Peter time. The marine fossils were found at 20 feet above the base of the Harding and at higher horizons, showing that it is clearly marine practically from top to bottom.

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[220] Darton, N. H., Geology and underground water resources of the central Great Plains; U. S. Geol. Survey, Prof. Paper No. 32, 1905, p. 78.

[221] Folio 7.

[222] Walcott, C. D., Preliminary notes on the discovery of a vertebrate fauna in Silurian (Ordovician) strata; Bull. Geol. Soc. America, vol. 3, 1892, pp. 153-171.

Above the Harding rests with apparent conformity the Freemont limestone. Cross[223] and Darton[224] both assign to it a maximum thickness of about 270 feet. It contains practically no shale or sandstone beds, and is only slightly arenaceous. Again, as in the case of the Beekmantown, this would suggest deposition at considerable distance from land, or if near the land, the surface must have been low, and yielding little clastic material. This and other facts presented would suggest that the Beekmantown once probably spread widely over this region, that the area then emerged, and was eroded deeply enough to expose the pre-Cambrian, which yielded the clastic material of the Harding, but that this land was again largely submerged by Freemont time.

The Fremont has also yielded a considerable fauna[225] which is listed below.

Fauna of the lower 10 feet of the Freemont.

	Range.
Stromatopora, sp. undet	
Receptaculites oweni Hall	Bl. R.-Tr.
Receptaculites, sp. undet	
Streptelasma, sp. undet	
Zaphrentis, sp. undet	
Halysites catenulatus Linn	Tr.-Cob.
Monticulipora sp.?	
Phyllopora, sp. undet	
Columnaria alveolata Goldfuss	St. R.-Rich.
Favosites, sp. undet	
Heliolites, sp. undet	
Echinosphaerites, n. sp	
Glyptocrinus, sp. undet	
Strophomena (Rafinesquina) alternata Conrad	Tr.-Rich.
Streptorhynchus filitextum Hall (Strophomena incurvata)	St. R.-Bl. R.
Orthis tricenaria Conrad	St. R.-Bl. R.
Ortois, sp. undet	
Streptorhynchus (Strophomena) sulcatum Verneuil	Rich.
Streptorhynchus sp. undet	
Orthis (Platystrophia) biforata Schlotheim	Ord.-Sil.
Orthis flabellum ?	
Orthis (Dinorthis) subquadrata Hall	Rich.
Rhynchonella (Rhynchotrema) increbescens Hall	Tr.
Rhynchonella (Rhynchotrema) dentata Hall	Tr.-Rich.
Camarella, sp. undet	
Ambonychia bellistriata Hall	Tr.
Ambonychia, 2 sp. undet	
Modiolopsis (Eurymya) plana Hall	Bl. R.
Modiolopsis, 2 sp. undet	
Cypricardites, 2 sp., undet	

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[223] Folio 7.

[224] Prof. Paper 32.

[225] Walcott, C. D., Bull. Geol. Soc. America, vol. 3, 1892, pp. 153-172.

	Range.
Tellinomya, sp. undet	
Metoptoma, sp. undet	
Helicotoma sp	
Murchisonia (Lophospira) tricarinata Hall	**Bl. R.**
Murchisonia, 2 sp. undet	
Cyclonema bilix Conrad	**Rich.**
Cyclonema (Gyronema) percarinata Hall	**Tr.**
Cyclonema, sp. undet	
Bellerophon bilobatus Sowerby (Sinuites cancellatus)	[illegible] Rich
Endoceras proteiforme Hall	Bl R.-Rich
Ormoceras (Actinoceras) tenuifilum Hall	Bl R.
Ormoceras (Actinoceras) crebriseptum Hall	Cin
Orthoceras vertebrale Hall (Cycloceras olorus)	Bl R.-Tr
Orthoceras multicameratum Hall	**Bl. R.**
Gomphoceras powersi James?	**Bl. R.**
Gomphoceras, sp. undet	
Cyrtoceras, 2 sp. undet	
Lituites, sp. undet	
Asaphus, like A. platycephalus (Isotelus gigas)	**Tr.-Rich.**
Illaneus crassicauda (americanus) Whalen	**Tr.**
Illaenus (Bumastus) milleri Billings	**Bl. R.**

Freemont fauna 225-245 feet above base.

Streptelasma corniculum Hall	**Tr.**
Streptelasma, 2 n. sp	
Columnaria alveolata Goldfuss	**St. R.-Rich.**
Favosites gothlandicus Lamark	**Sil.**
Pleurodictyum, n. sp	
Halysites catenulatus Linn	**Tr.-Cob.**
Monticulipora, 2 sp. ?	
Cyclocrinus sp. ?	
Leptaena (Plectambonites) sericea Sowerby	**Bl. R.-Rich.**
Leptaena sp. undet	
Strophomena (Rafinesquina) alternata Conrad	**Tr.-Rich.**
Strophomena alternata nasuta Conrad (Rafinesquina nasuta)	**Cin.**
Streptorhynchus filitextum Hall (Strophomena incurvata)	**St. R.-Bl. R.**
Streptorhynchus (Strophomena) nutans James	**Rich.**
Streptorhynchus (Strophomena) planoconvexus Hall	**Mays.**
Streptorhynchus (Strophomena) planumbonus Hall	**Rich.**
Streptorhynchus subtentum Conrad? (Strophomena planumbona)	**Rich.**
Orthis (Dinorthis) subquadrata Hall	**Rich.**
Orthis (Dalmanella) testudinaria Dalman?	**Bl. R.-Rich.**
Rhynchonella (Rhynchotrema) capax Conrad	**Rich.**
Rhynchonella (Rhynchotrema) increbescens Hall	**Tr.**
Pterinea, sp. undet	
Tellinomya (Ctenodonta) dubia Hall?	**Tr.**
Tellinomya (Ctenodonta) levata Hall?	**Tr.**
Tellinomya ventricosa Hall (Ctenodonta gibberula)	**St. R.-Bl. R.**
Cypricardites, 3 sp. undet	
Modiolopsis (Colpomya) faba Conrad	**Tr.**
Modiolopsis sp. ?	
Metoptoma sp. undet	
Helicotoma planulata Salter	**Bl. R.**
Helicotoma sp. ?	
Trochonema beachi Whitfield?	**Bl. R.**
Murchisonia milleri Hall (Lophospira bicincta)	**St. R.-Rich.**
Murchisonia pagoda Salter (Eotomaria prisca)	**Bl. R.**
Murichisonia, 3 sp. undet	
Subulites (?) sp. undet	

	Range.
Bucania (Salpingostoma) buelli Whitfield	Bl. R.
Bucania (Tetranota) bidorsata Hall	St. R.-Tr.
Cyrtolites, sp. undet	
Orthoceras (Spyroceras) anellum Conrad	Bl. R.-Tr.
Orthoceras junceum Hall	Bl. R.-Tr.
Endoceras proteiforme Hall	Bl. R.-Rich.
Gomphoceras sp. ?	
Leperditia sp.?	
Ceraurus (Ceraurinus) icarus Billings	Rich.
Asaphus platycephalus Stokes (Isotelus gigas)	Tr.-Rich.
Asaphus megistos Locke (Isotelus maximus)	Tr.-Rich.
Illaenus (Bumastus) milleri Billings	Bl. R.
Proetus (?) sp. undet	
Proetus (?) sp. ?	

This fauna has strong late Black River and Trenton relationship, and is very closely related to the Platteville and Galena faunas of the Mississippi Valley region. It is interesting to note the presence of *Halysites catenulatus* in this and in the Missouri fauna (p. 32). The numerous Richmond forms suggest the extension of the Fernvale into Colorado, probably involving a hiatus within the Freemont limestone.

In the Bighorn Mountains and Black Hills the Bighorn limestone of Trenton and Richmond age rests directly on the Cambrian Deadwood formation, nothing equivalent to the Beekmantown or St. Peter being present.[226]

SUMMARY.

The general stratigraphic relations outlined in the preceding pages are summed up in the sections and maps constituting Plates I-IV.

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[226] Darton, N. H., Bald Mountain-Dayton Folio, U. S. Geol, Survey, Folio 141. 1906.

CHAPTER II

CHARACTER OF THE ST. PETER SANDSTONE.

COMPOSITION OF THE ST. PETER.

General statement.

In discussing the character and origin of the St. Peter sandstone, much emphasis has heretofore been placed on the exceptional purity of the sand. Information on this point has previously consisted of a comparatively few scattered analyses of samples of the sandstone from various states. The writer has had prepared for the economic side of this study 22 analyses of typical samples of the St. Peter sandstone, chosen from all parts of the state of Missouri where the formation outcrops. He has also had made 2 analyses of the Everton sandstone, which is clearly a part of the St. Peter group. These results have already been published for economic purposes.[1]

These analyses completely justify the usual statements that the formation is an exceptionally high grade silica sand. Of the total of 24 samples analyzed, 17 contain over 99 percent silica, and 9 of those contain over 99.5 percent. It may be contended that these samples, chosen for a study of the glass sand possibilities, do not represent a fair average of the formation as a whole. This contention may, perhaps, be in part just. The samples, however, were all unwashed, and the 17 already cited represent the natural sand, in its purest development, where it was thought it had possibilities of economic exploitation.

As a matter of scientific interest, eight samples were chosen from widely separated localities, believed to represent a fair average of the least pure parts of the formation. Among these, the silica content varies from 96 to 99½ percent. The significance of the quantity and kinds of impurities will be discussed in later paragraphs.

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[1] Dake, C. L., The sand and gravel resources of Missouri: Mo. Bur. Geol. and Mines, vol. XV, p. 122, 1918.

The results presented above show conclusively that the St. Peter is a remarkably pure quartz sand, averaging, throughout the State of Missouri, well above 98 percent silica. This is entirely comparable to results arrived at elsewhere. No such comprehensive study of the composition of the formation has been made, in other localities, and heretofore, there has been some question whether the results attained were entirely representative. The two Everton samples which were analysed under the writer's directions showed respectively 99.30 and 99.50 percent silica, and are thus in every way comparable to the St. Peter.

So far as the writer has been able to learn, no such complete and systematic sampling has ever been done for any other sandstone formation, so that fair comparisons are difficult to make. Clarke[2] gives two composite groups, one of 253 sandstones, which average 78.66 percent silica, and one of 371 samples, which average 84.86 percent. These figures show only that the St. Peter is much purer than the general range of sandstone. Clarke[3] gives one analysis of the Potsdam from Albeman, Wisconsin, which shows 99.42 percent silica, and Buckley[4] gives one from the same formation and locality which contains 98.64 percent.

Colony[5] gives seven analyses of the Potsdam in New York that run as follows in percent silica, 95.08, 95.45, 96.83, 98.82, 98.84, 98.99, 99.22.

These cases show that selected phases of the Potsdam, at least, are of the same order of purity as the St. Peter, the difference, in general, being less marked than has generally been supposed.

In a study of this sort, considerable interest attaches to the nature and amount of the various impurities present. The more important of these, iron oxide, clay, and carbonate, demand a somewhat more detailed consideration.

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[2] Clarke, F. W., The data of geochemistry; Bull. U. S. Geol. Survey, No. 616, p. 541, 1916.

[3] Loc. cit.

[4] Buckley, E. R., Building and ornamental stone of Wisconsin; Bull. Wis. Geol. and Nat. Hist. Survey, No. IV, p. 231, 1898.

[5] Colony, R. J., High-grade silica materials for glass, refractories, and abrasives; New York State Museum Bulletins 203-204, 1919, p. 22.

Iron oxide in the St. Peter.

In the analyses referred to above, the white samples of the formation selected because of their probable economic value, sixteen in number, ranged from 0.043 to 0.11 percent ferric oxide. While no separate tests were made for the occurance of manganese, any traces which may have been present would, without doubt, have come down with the iron, and are included in the figures given for ferric oxide. All the iron present was determined as ferric, no tests being made to distinguish ferrous iron. Considering the very small amounts of iron involved, and the fact that, from its occurrence, a very large part of it was undoubtedly in the ferric form, this assumption is certainly justified. There is no evidence whatever that the iron in the above purer samples is infiltrated. It may be present as a film on the grains, but is in such minute amounts that its position and origin quite escape detection.

Other less pure samples were also analysed. In eight of these, the ferric oxide ranged from 0.10 to 0.94 percent. The most ferruginous sample the writer was able to find, a sample that exhibited a deep reddish brown color, showed only 0.94 percent of iron oxide. Among these more ferrigunous samples, the iron was present in two distinct methods of distribution.

By far the most important of these two methods is clearly related to the present erosion surface of the formation. Where exposed in cliffs, with a protecting cover of younger limestone, the St. Peter is exceptionally white from top to bottom, and this color is indicative of a high degree of purity, particularly of freedom from iron oxides, either ferrous or ferric, numerous analyses of white samples of the sandstone showing invariably under 0.11 percent iron oxide. On the other hand, where the protective cover is removed, and the sandstone is exposed to the wash from highly ferruginous soils above, the content of iron is invariably appreciably increased, and this increase is evidenced to the eye by a marked red or reddish-brown color. As a rule, the more gentle the slopes, and consequently the deeper the soil, the higher the iron content in the underlying sandstone. High iron content is usually also associated with high clay content, and results largely from the mechanical infiltration of fine ferrigunous clay. There is no definite horizon at which this occurs, the infiltration taking place wherever the formation is covered with ferruginous soils. As a rule, it occurs more abundantly near the base, not as a result of the stratigraphic position, but simply because the top of the formation is more often exposed in steep slopes and cliffs, while the base is more often in low flat, deeply soil covered ledges. That this iron content is a recent infiltration is also shown by the remarkable whiteness of the St. Peter in deep well borings at several points.

Another method of distribution of the iron consists of horizontal bands, from one to four inches thick, of faintly reddish-brown sandstone. These were visible only on freshly quarried faces and were termed iron seams by the quarry operators. Similar seams were noted on a freshly caved natural cliff of the formation, near Perryville, Missouri. Analysis of such a seam from the quarry of the Pittsburg Plate Glass Company, at Crystal City, Missouri, shows only 0.14 percent iron oxide. This occurs partly as a coating on the grains, and partly as staining in a fine red clay. Part of the iron from such seams washes out with the clay, the cleansing requiring but little agitation.

Certain explanations offer themselves, for the presence of these ferruginous seams. One is that they represent infiltration, along more pervious beds, where ferruginous solutions may have been concentrated. Another is that they represent former levels at which the water table stood for some time, allowing oxidation on the surface of the water. Still another is that the layers were slightly more iron stained material than the rest of the formation at the time they were laid down.

The hypothesis that suggests infiltration along certain more susceptible layers appears to be untenable, because of the apparent homogeneity in texture, porosity, and composition, of the material through which the bands pass.

More plausible is the suggestion that the bands mark former ground water levels, along the surface of which there has been sufficient oxidation of slightly ferruginous solutions to produce a faint coating of iron on the grains. These bands are clearly not related to present water levels, and there seem to be no available evidences of former corresponding topographic levels. The inability, however, to correlate these bands with any external evidence of former water levels, is probably to be expected.

The lack of oxidation features above the band, to the top of the formation seems a little surprising inasmuch as all that part of the formation above the water table was subject to the same oxidizing conditions. This may perhaps be explained by the remarkable porosity of the sandstone, which would not hold solutions sufficiently long, above the general water level, to permit of appreciable oxidation of the solutions.

The thinness of the bands is also surprising, since it would seem to point to a rather unusually permanent water stand. The bands are rarely over six inches wide, and usually only three or four inches. It is difficult to conceive of fluctuations of the water table being limited to such amounts, those noted at the present time ranging through much greater distances.

A feature that seems to favor the water table hypothesis, is the fact that these bands, in some places at least, are apparently more nearly horizontal than the faint traces of bedding and cross-bedding which seem to be intersected by the color bands. This would point to a later origin for the iron oxide. That a few of the bands are slightly inclined is not surprising, since the water table, even in a formation so homogeneous, is by no means an absolutely flat surface.

Horizontal structural features related to former water levels are not unknown in other rocks. The writer has noted such horizontal bands of slightly more cemented material intersecting cross-bedding in glacial gravels in Nodaway county, Missouri; and horizontal structures resulting from calcareous cementation passing through cross-bedded layers of the San Juan formation, in Porto Rico, are ascribed by Berkey to old water levels.[6]

Dr. Berkey has also called the writer's attention to irregular coloration of the lower Potsdam of Wisconsin, and Minnesota. Similar irregular coloration has been noted by the writer, in the LaPlata sandstone, near Torrey, Utah. This coloration appears to be secondary but whether from infiltration or oxidation is uncertain. In some cases it may be superficial staining but in other cases, it certainly penetrated the formation some distance.

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[6] Berkey, C. P., Geological reconnaissance of Porto Rico; Annals N. Y. Acad. Science, vol. XXVI, p. 45, 1915.

A microscopic study of the ferruginous St. Peter bands shows that a few grains have undergone quartz enlargement, and on these, the iron stains show a a faint discoloration on the new crystal surfaces. To this extent, at least, the addition of iron was later than the enlargement, and hence (p. 183) presumably later than the deposition of the sand. While the proof holds only for the recrystallized grains, the presumption is that it applies equally to all the iron stains.

The problem is somewhat puzzling, and by no means definitely solved. Nevertheless the writer inclines to the view that the position of the bands is related to former water levels. Since the answer is uncertain, however, it is well to consider the possible situations that would result, if the iron content is considered to be original. Here arise two cases. The one is that it was an original coating on the grains, before their actual deposition; the other, that it represents a surface infiltration on the top of a mass of the accumulating sand, before its complete burial.

The first of these suppositions, which might lead to the conclusion of desert origin, with typical desert varnish, seems to be successfully controverted by the two following points. First, part of the iron is easily removed by washing, being present as a fine red clay, which would not be likely to be the case with a formation subject to constant wind drift. And second, if it were a desert varnish, it should not be limited to occasional thin bands, but should be present in a considerable part of the formation.

If, then, the iron content is contemporaneous, it must have been deposited in occasional patches as an infiltration on the surface of the accumulating sand. This might be accomplished in stagnant pools, if the upper surface of the formation were above sea level. It is perhaps more difficult to understand how such an impregnation of iron in the ferric state could occur below sea level. Nevertheless, the evidence afforded by the ferric ores of the Clinton seems to demonstrate beyond dispute that such conditions can obtain.

Summary.—To sum up the significance of the presence of iron oxide, emphasis must again be placed on the fact that much the larger part of the iron oxide is clearly later infiltration, but there are certain ferruginous bands which may be either original or secondary. The writer inclines to the view that they are secondary, and related to the old water levels. It is realized however, that the evidence is not very conclusive, and the bearing of possible primary origin is reviewed. The conclusion is reached, that the iron is not an old coating on the grains, and if primary in any sense, must represent contemporaneous impregnation. It is shown that this could occur with either marine or terrestrial conditions. It is recognized that red formations are characteristic of terrestrial deposits. It is believed, however, that the rarity of such bands in the St. Peter, together with a consideration of the several ways in which they may have been produced, renders of very doubtful value any argument for terrestrial origin of the St. Peter, based on their occurrence.

Clay in the St. Peter.

Very small quantities of alumina are universally present in the St Peter sandstone. Analyses of 16 samples selected as possible glass sands, and coming from widely separated localities in Missouri, show alumina varying between 0.013 and 0.46 per cent. This would correspond to a range of from 0.04 to 1.17 per cent of kaolin, assuming all the alumina to be present in that mineral. This is in close accord with already published analyses. Such quantities of clay are too low to be especially significant, except to emphasize the rarity of that substance.

The very red phases of the sandstone, six analyses in all, show higher alumina content, the range being from 0.34 to 1.17 per cent alumina, corresponding to a range of from 0.86 to 2.96 per cent kaolin. The higher clay content here has already been shown to accompany higher iron content and has been attributed to the introduction mechanically of fine ferruginous clay, where the sandstone is completely exposed by removal of its protective cover of limestone. These high clay phases are always closely related to the erosion surface. Since they are of later introduction, they have no significant bearing on the origin of the formation.

Clay also occurs, and in even greater percentages, in certain greenish layers which are locally termed mud seams. These were noted, both in quarry faces and in freshly caved exposures on certain hill slopes. At most points such mud seams are few and thin. However, in Section 34, T. 43 N., R. 3 E., in Jefferson county, Missouri, a twenty-foot cliff of the formation is exposed, in which the aggregate thickness of the clayey bands approximates at least one-fourth of the total twenty feet.

The only one of these seams to be analyzed occurs in the quarry of the Pittsburg Plate Glass Company at Crystal City, Missouri. The alumina content is 1.037 per cent, corresponding to about 2.62 per cent kaolin. Other seams noted apparently carried a considerably higher clay content than this. No clay galls or pellets were noted, in connection with these clay seams, such as are described in some desert sands.

Clay particles in a sandstone might perhaps be expected to have somewhat the same significance as the presence of mica, a criterion which will be discussed at more length in a later paragraph (p. 145). The presence of much fine material in general has been presumed to argue against eolian origin and its absence in favor of such an origin.

In general it may be said that, where the material is, at least in part, derived locally, and there is an abundant source of clay, its presence is to be expected, even in a wind-drifted sand. Such is presumably the cause of the considerable clay content in the LaPlata (Jurassic) sandstone of the Colorado Plateau. This formation, which seems to be one of our best examples of an eolian deposit, was laid down on an extensive clay plain of the Dolores (Chinle) formation, and no amount of wind drifting could entirely remove the clay content. In such a case the formation might be expected to contain much clay, whether of marine or terrestrial origin.

On the other hand, where the material has been transported for long distances, as will be shown to be the case with the St. Peter sandstone, the sorting is, of course, much more perfect and, whatever the transporting agent, the clay will be more or less effectively separated from the sand. It is clear that the separation has been peculiarly effective in the St. Peter.

It has sometimes been stated that the entire absence of clay in that formation constituted evidence of its wind-blown origin. In the first place, this line of reasoning is not quite exact, inasmuch as the St. Peter, while without doubt remarkably low in clay, does contain notable clay seams. And moreover, the general absence of clay can quite as well be accounted for on other grounds. It will be shown later that the St. Peter was in all probability derived from the erosion of the Potsdam sandstone farther to the north and northwest. That formation has already been shown to have a purity only slightly inferior to that of the St. Peter itself. In the nine analyses already referred to, the Potsdam is shown to contain 0.31[7], 0.44, 0.46, 0.52, 0.73, 1.10, 1.18, 3.04, and 3.27 per cent Al^2O^3, corresponding to 0.78, 1.12, 1.16, 1.32, 1.85, 2.76, 2.98, 7.68 and 8.28 per cent kaolin. assuming that all the alumina is present in that mineral. In New York, however, sericite, is reported in places. These, of course, represent selected exmples. Still it is obvious that the Potsdam was already a well-sorted sand, much purer than the average sandstone, and but little additional sorting is required, to derive from such a source, a sandstone as free from clay as the St. Peter. Any agent other than glaciers, capable of transporting the sand the hundreds of miles involved in the case, is believed to be adequate to perform the degree of sorting demanded.

Another consideration which is certainly involved, and to which little attention has been given, is the probability of wind cleansing in the area from which the St. Peter was derived. Wherever the St. Peter may have been deposited, on the land, or in the sea, it was derived from a land area which was, in Ordovician times, probably without a protective cover of vegetation. If, as the writer believes, this area was the site of erosion of the older Cambrian (Potsdam) sandstone to the north and northwest, where the bordering remnants of Potsdam are still a very friable sandstone, conditions must have been ideal for the drifting of loose sand and the formation of dune areas. Even though the St. Peter were deposited in the sea, it is almost inconceivable that it could have escaped thorough wind-drifting in such an area. Consequently its freedom from clay, even thought it might point to wind-sorting, would still fall far short of proving that the St. Peter was either carried into its present distribution by wind, or deposited by that agent.

What the cause may be that produced so pure a sandstone in the Potsdam, though it is a closely related problem of great interest, is one aside from the scope of this paper, and one for the solution or even discussion of which the writer has not the essential field data. From the nature of the Potsdam sources in the mixed rocks of the pre-Cambrian, however, it would appear that the solution of the latter problem is really by far the more difficult one, because while there are fairly pure quartzites, even in the pre-Cambrian, the folding and distribution is such as to preclude the supposition of derivation from any single source.

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[7] The amounts 0.31 and 1.10 include Fe^2O^3.

Summary.—The St. Peter has been shown to be, in its general composition, remarkably free from clay, though numerous clay seams occur throughout the formation. The freedom from clay, however, is not greatly in excess of the ranges of purity in the Potsdam sandstone, from which the St. Peter was probably derived. Granting the greater ability of wind to remove the lighter and finer constitutents, such as clay and mica particles, compared with the power of water to perform the same work, it still appears obvious that either agent, working upon a source of supply which had undergone so great preliminary sorting as the Potsdam, could effect the degree of cleaning demanded. And even if this conclusion is doubted, there can be no question whatever that there could have been additional wind sorting in the supply region, without the necessity of concluding that the St. Peter was carried to its destination, or deposited, by the wind. The presence or absence of the clay, then, cannot be taken as a criterion for either marine or terrestrial deposition of the St. Peter. The value of the clay seams as an indication of bedding will be discussed in a later paragraph, devoted to the significance of stratification.

Mica in the St. Peter.

The presence or absence of mica[8] has been considered as a possible criterion in determining whether a sand was laid down by wind or water. It must be understood, of course, that this applies only to original clastic grains of mica, not to those flakes which may have developed secondarily in the rock, after its deposition. The former type can usually be identified by being more or less worn. The significance of mica rests on the conclusion that wind has a greater power of separating out and entirely removing that substance than water could have. The fineness of the particles and their flat character render them particularly susceptible to being blown away. And the higher velocities of the wind and its greater sweep probably render it a better agent for the complete removal of excessively fine material. The principle involved seems to be fundamentally sound. A general statement of its application would be that the presence of mica in a formation points to deposition by some agent other than wind while its absence more probably signifies eolian origin. This statement needs modification, however, in several important directions.

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[8] Galloway, J. J., Unpublished manuscript.

First, the presence of mica involves a source for at least part of the sand, in which mica already exists. Second, if the sand is still close to its source, even wind will have failed to remove most of the mica. Dr. Galloway states that the only examples of wind-blown sands showing mica, among those studied by him, were clearly near their source, and incompletely worked over. Third, the absence of mica may simply point to a source for the sand, in which was no mica, to begin with. And fourth, with sufficient time and distance of transport, water might be expected to remove the mica, even though much more slowly and less effectively than was done by the wind. This would be particularly true, if the formation from which the sand was derived was itself nearly free from mica.

That water can actually accomplish this is clearly suggested by experiments conducted by Dr. Galloway,[9] though he has not called attention to their significance in this direction. The experiments were carried on to determine the rate and degree of rounding of grains. Of the minerals, quartz, feldspar, hornblende, and mica, the latter was the first to be notably rounded. The material removed from each grain during the process must have been ground to an impalpable powder, in which condition it would probably not be recognizable as mica, even if it did not go entirely into solution, or become altered, a fate rendered particularly probable by its fine state of division. The rounded remnants must continue to grow smaller, indefinitely, since it has been shown[9] conclusively, contrary to general belief, that even the minute grains continue to be worn and rounded. Thus, if the process continues sufficiently long, even water transportation will result in the destruction of the mica particles.

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[9] Galloway, J. J., The rounding of sand grains by solution; Amer Jour. Sci., vol. XLVII, 1919, pp. 270-280.

Mica is practically absent in the St. Peter. To say, however, that its rarity points to eolian origin of the sand, without careful consideration of the modifications suggested above, would be to ignore highly important possibilities. In the first place, examination must be made of the source of the St. Peter. As has already been stated, it will be shown in later pages that its derivation can be referred with considerable confidence to the Potsdam. This sandstone itself, except in its lower part, is strikingly free from mica, over large areas, though a little sericite is reported in places.[10]

Furthermore, the sands of the St. Peter, in addition to being derived from a very pure sandstone, have been transported very long distances, and might be expected to show a less mica content than the sands from which they were derived, due to actual destruction of mica particles resulting from very fine comminution and subsequent weathering.

Summary.—The absence of mica in a sandstone formation may be due to removal of the flakes present in the original material, and it is granted that this can probably be done more effectively by wind than by water. On the other hand, it may be accounted for by the absence of mica in the original material from which the sands were derived, and it is believed that this is at least an important factor in the absence of mica in the St. Peter formation.

Heavy minerals in the St. Peter.

The presence or absence of heavy minerals, such as magnetite, tourmaline, garnet, zircon, apatite, and rutile, have been suggested[11] as a criterion for detecting the origin of water-laid or wind-laid sands. The presence or absence of such minerals in the source of the sand, and the proximity of the sand to its source are here also modifying factors. No sand will have heavy minerals, unless it is derived, in part at least, from a source in which such minerals occur. And if the deposits are in close proximity to their source, no sorting agent would completely remove such heavy minerals.

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[10] Colony, R. J., New York State Mus. Bulletins 203-204.

[11] Galloway, J. J., Unpublished manuscript.

With long transportation, these minerals would tend to be removed, either by wind or water. Quite probably wind might be the most effective agent. Nevertheless, water would accomplish considerable, in this direction, if the distance of transport were considerable.

A careful examination of samples of the Potsdam shows a notable absence of the heavy minerals. Two samples from Wisconsin, one from near Madison, and one from the Dalles of the Wisconsin River, each showed an occasional grain of some dark mineral, other than quartz. These were conspicuous however, by their exceptional rarity. In specimens from New York studied by Mr. Colony[12] occasional zircon, rutile, and tourmaline fragments were noted. They seem to be more abundant than in the material from Wisconsin. Even so, Mr. Colony[13] reports that they are by no means abundant and this conclusion was borne out by the writer's studies. Their relatively greater abundance in New York is perhaps attributable to the proximity of the pre-Cambrian highland of the Adirondacks, which seems to have persisted as an island at least throughout Potsdam time. Such monadnocks were rare in Wisconsin, and the few known were largely themselves rather pure quartzites.

The base of the Potsdam is known to be less pure than its upper part, and quite probably contains a larger proportion of heavy constituents. That its upper portion is exceptionally free from such minerals, especially in Wisconsin, which seems to be the region nearest to the original source of the St. Peter, is beyond dispute.

Conclusions.—The freedom of the St. Peter from heavy minerals is not remarkably greater that that of its source, the Potsdam, and certainly is not such as to demand any unusual degree of sorting. It does not, therefore, seem to be a criterion of much weight, in this particular case.

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[12] Colony, R. J., High grade silica materials for glass, refractories, and abrasives; New York State Museum Bull. 203-204, 1919.

[13] Personal communication.

Carbonates in the St. Peter.

The carbonate content of the St. Peter is very low. Combined MgO and CaO, as shown in 34 analyses, most of which were made under the writer's direction, ranges from a minimum of 0.01 per cent to a maximum of 1.24 per cent. This of course is exclusive of limestone beds in the formation, and applies only to the actual sandstone. The last figure 1.24 per cent, was found in a limey bed near the top of the formation, and is exceptional. Excluding it, the maximum is 0.47 per cent, or about one per cent of carbonates. This content is certainly very low for a marine formation, but actually is somewhat greater than that given in the several analyses of the Potsdam already mentioned, where the range runs from 0.00 to 0.13 per cent of combined CaO and MgO, or about a fourth of one per cent of carbonates. Since, however, there are some who insist that much of the Potsdam is non-marine, the value of the comparison may be questioned. Analyses of the Oriskany presented by Mr. Colony[14] show respectively 0.02 and 0.04 percent CaO and only traces of MgO, or less than 0.1 per cent combined calcium and magnesium carbonates; however, the marine origin of part of this sandstone has also been questioned. While no analyses have been made of the Roubidoux, petrographic studies show that it, too, contains just as small a lime content; and it is clearly a marine formation.

Further than this, the St. Peter is very porous, and carbonates are relatively soluble. It is, therefore, more than probable that the distribution of carbonates in the formation is not that originally produced during sedimentation. That carbonate has been leached out in some parts and added in others, depending on the character of the penetrating solutions, is quite to be expected. It is thought, therefore, that the carbonate content of the St. Peter is not capable of throwing much light on its origin.

The suggestion of Ulrich[15] that the St. Peter was once everywhere calcareous, and that the lime has later been leached out by circulating waters, does not seem to be in accord with conditions known by the writer, from deep wells in Missouri, where the formation seems little more calcareous than at the surface.

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[14] Colony, R. J., New York State Mus. Bulletins 203-204.

[15] Ulrich, E. O., Revision of the Paleozoic systems; Bull. Geol. Soc. America, vol. 22, p. 529, 1911.

The presence of lenses of dolomitic limestone within the St. Peter can hardly be considered as a factor of composition, and while such beds are of the greatest significance their discussion is reserved for another place (p. 212).

Conclusion.—The carbonate content of the St. Peter is very small, but is essentially of the same order of magnitude as that of the Potsdam, and of other sandstones, some of which at least, are clearly marine. It is felt, therefore, that the carbonates throw little light on the origin of the formation.

Absence of chert in the St. Peter.

One of the most notable features of the purity of the St. Peter is the absence of chert. Throughout the area studied in Missouri, the St. Peter rests with marked unconformity on the surface of the Jefferson City, Cotter and Powell dolomites. These dolomites are notably cherty, and very exceptionally so at many places where seen in contact with the basal St. Peter. The abundance of chert at this horizon was noted by other workers in the area, to whose field notes the writer has had access. This concentration of chert is believed to be in the nature of residual material, since in many places it is embedded in a nearly structureless mass of mixed clay and sand, with finer particles of chert. This grades up, in places, into a typical basal conglomerate, in which the pebbles are chert and blocks of limestone, sometimes rather large, embedded in a matrix of characteristic St. Peter sand grains.

The surprising feature is that this chert is limited, always, to the lower few feet of the sandstone. Not even the finer particles are found more than a few feet above the base.

Had the St. Peter sand been drifted into the region by the wind, in a series of migrating dunes, it is obvious that the rock floor would at many times and at many places have been exposed to the scour of the wind. The St. Peter extends over hundreds of square miles, in a mantle averaging not over 100 feet thick, and dunes, drifting sufficiently to carry this mass of sand into the region, from some external source (and there is obviously no local source) would necessarily uncover many times the rock floor, especially the higher knobs. This would allow the finer chert particles to migrate up the dune slopes.

Under such conditions, the chert, a considerable amount of which is fine enough to be wind drifted, would mix intimately with the sand. Its specific gravity is so near that of quartz, as to fail entirely in assuming separation, while it is also so near the quartz in hardness that it surely could not be assumed to be destroyed by abrasion.

When the eolian theory of origin of the Sylvania was advanced, the criticism was suggested, "should there not occur in the sand clastic grains of dolomite, this being the rock upon which the deposit rests?" To this question Sherzer[16] made reply:

> "Such clastic grains, if introduced, would be relatively small in amount and soon be ground to powder . . . Furthermore, after the land had once become mantled with the eolian formation, it would have been protected from further wind erosion."

While both of these points may very well be true for the Sylvania, they certainly are not satisfactory explanations in the case of the St. Peter. The very nature of Sherzer's answer indicates that he admits the principle, but limits its application, in the particular case. In the rocks underlying the St. Peter there was a source of foreign material, the chert, which would not "soon be ground to powder", and hence should appear in the St. Peter, and a sand like the St. Peter, averaging under 100 feet thick over thousands of square miles, on a surface with over 100 feet of relief, would not allow the floor to become "mantled with the eolian formation . . . and protected from further wind erosion."

If one were to assume a slightly dissected region rather quickly depressed below the zone of active wave work, with both streams and waves contributing sand, and with a series of off-shore sands gradually encroaching into the deeper waters, conditions would prevail for the burial of the cherty phase described above with but little working over and commingling of the chert with the overlying sand. This is believed to constitute a very strong argument in favor of introduction of the sand into the region through wave work rather than by migration of sand dunes, in an extensive desert.

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[16] Sherzer, W. H., Criteria for the recognition of the various types of sand grains; Bull. Geol. Soc. America, vol. 21, 1910, pp. 625-661.

TEXTURAL CHARACTERISTICS OF THE ST. PETER.

Much emphasis has heretofore been placed on the character of the St. Peter grains. In fact, most of the arguments in favor of the eolian origin of the formation have been based on textural character. Any study, however, should discriminate between those criteria that have a bearing on the production of the sands, those that give evidence as to mode of transportation and those that throw light on conditions of deposition. Textural criteria, so far as they are valid at all, can give evidence only on the first two points. To determine, on the other hand, the conditions of deposition, the most dependable final criteria must always be the broader structural and stratigraphic relations, for these alone are definitely those imposed on the sands at the time of origin of any formation as such, regardless of the source of the material. On the other hand, peculiarities of grain may be inherited from earlier formations which were destroyed to produce later stratigraphic units. This principle, which is of the utmost importance, has been entirely ignored by many students of the problem. Others have recognized it, and stated it, at least in part.[17] But it has seemed to the writer that textural criteria have been emphasized by many to the extent of ignoring other vital factors.

Even in the matter of textural criteria, it seems that both in principle and application there has been much misinterpretation. It has seemed worth while, therefore, to go over the most important of these, in the way of a brief review. It is quite beyond the limits of available space, to sum up what each previous investigator has said, regarding these criteria. But it is worth while to review the evidence, in an endeavor to point out apparent misconceptions, and also apparent misapplications of the importance of texture. The more important criteria of this type are size of grain, uniformity of grain, degree of rounding, and frosting and pitting of grains. Each will be considered in turn.

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[17] Berkley, C. P., Paleogeography of St. Peter time; Bull. Geol. Soc. Am., vol. 17, 1906, pp. 229-250.
Trowbridge, A. C., Origin of the St. Peter sandstone; Iowa Acad. Sci., vol. XXIV, 1917, pp. 171-175.

SCREEN TESTS—POTSDAM SANDSTONE.

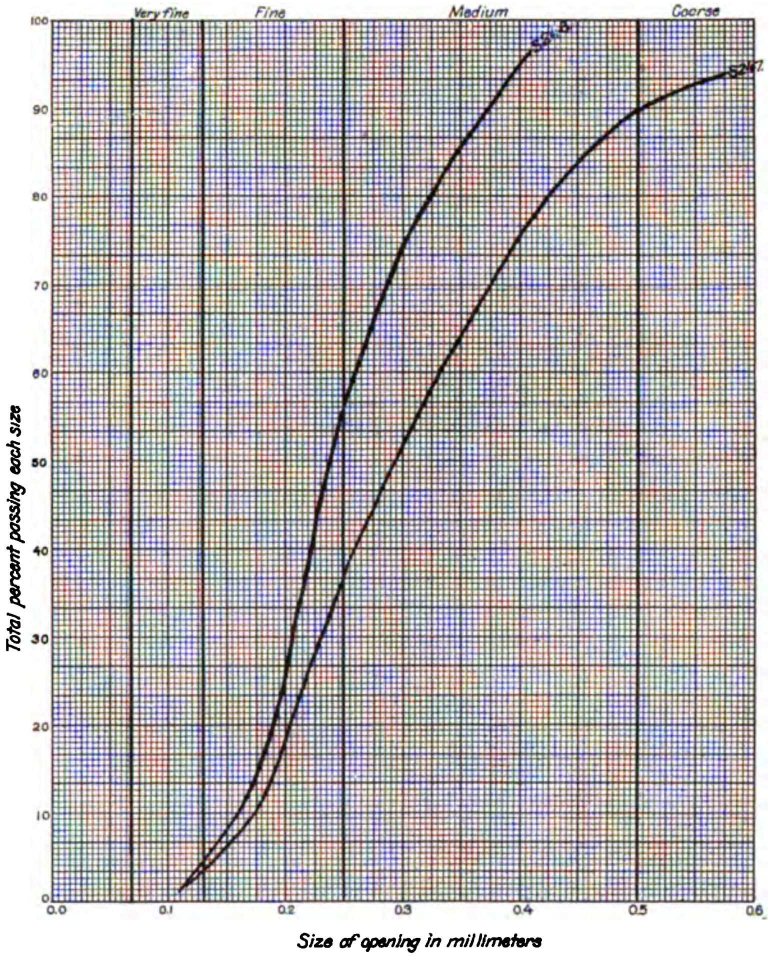

PLATE V.

S. 246. Potsdam sandstone, Madison, Wisconsin.
S. 247. Potsdam sandstone, Kilbourne, Wisconsin.
Samples furnished by F. T. Thwaites.

Size of Grain in the St. Peter.

So far as the writer is aware, Udden[18] was the first to contend that there is any particular relationship between size of grain and agent of transportation or deposition. He recognizes 4 sizes of sand, very fine, (1–16 to 1–8 mm.), fine (1–8 to 1–4 mm.), medium (1–4 to 1–2 mm.), and coarse (1-2 to 1. mm). In 47 wind-blown sands, of which he has made mechanical analyses, he has shown that all but one have the largest percentage lying within the grade called fine sand, ranging from 1–8 to 1–4 mm., and 43 have over 50 per cent lying within this class.

Concerning this fact Udden[19] remarks,

> "It will be noticed that in all these samples of dune sands, excepting the one collected by skimming the ridge of a ripple, the maximum ingredient is fine sand. In one instance ninety-two per cent consist of this grade, while in three cases it forms over eighty per cent of the bulk. Where lowest it forms forty-five per cent, and it averages sixty-five per cent in all the sands examined . . . . The occurrence of the maximum at the same or nearly the same point in nearly all the dune sand taken at many different locations, challenges our special notice."

He then goes on to explain at some length that the lower layers of the atmosphere, moving rarely over three miles per hour, can probably not, except under unusual conditions, handle large grains of sand, and finally sums up as follows:

> "Though it is not supposed that all dune sand is as uniform in composition as are the specimens described here, it seems probable that the wind forms drifts mainly of grains which measure from one-half to one-eighth of a millemeter in diameter."

While the writer is inclined to accept, in its larger features, Udden's conclusion that wind-drifted sand will consist largely of rater fine materials, he feels that these conclusions need to be modified and amplified in several important respects.

In the first place the size of grain in any wind-blown sand will be controlled, in one direction, by the size of grain in the available source. There will certainly be no grains coarser than those in the supply ground. This principle Udden has not completely overlooked, since he refers to the coarser material not entirely left behind in the derivation of two of the dune sands he describes. His conclusions, however, would be much more convincing, were he to show, in all cases in which the source could be traced, a comparison of the sizes in the source of supply, and in the resulting dune sand. The writer has not available materials for such a comparative study, but he feels that light could be thrown on the value of this particular criterion, by a study of the sort suggested, and hopes that some one may at some time be in a position to furnish desired information on this point.

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[18] Udden. J. A., The mechanical composition of wind deposits; Augustana Library Publications, No. I, 1898.

[19] Op. cit., p. 22.

A consideration of the size of sand grains not only involves a study of the range of sizes in the source, but also includes a careful consideration of the distances involved in the transportation. The greater the distance over which the material has been rolled (for of course the transportation of these sizes is almost wholly a matter of rolling, and not of true suspension) the smaller it will be in comparison with the sizes in the source of supply. This results from two causes, first a gradual leaving behind of the larger particles, and second, a gradual wearing of the particles in transit. The importance of this factor will again be emphasized, when the application of this criterion is made to the St. Peter sandstone. It could only be studied in a quantitative way, by tracing a series of wind-blown sands from a known source, and testing the sizes at varying distances from the supply ground. Such a study has not been possible to the writer, because of lack of material, but would constitute a valuable contribution to our knowledge of the subject. Reasoning, however, on a priori grounds, the general truth of the principle seems entirely valid. The application, while hinted at in Udden's discussion, seems almost to have escaped consideration.

Grabau[20] reports that the sand of the Libyan desert ranges from 0.5 to 2.0 mm. Since, however, he does not inform us as to the character or proximity of the source, nor whether the grains are worn quartz crystals or complex lithic fragments, the figures lose much of their value for comparative purposes.

The power of the wind to transport sand is assumed by Udden, and apparently quite correctly, to vary, just as in the case of water with the sixth power of changes in velocity. He modifies his statement, however, as follows:

> "Wind velocities are usually measured some distance above the ground, but the dune sand is moved only by the very lowest layers in the atmosphere. Now

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[20] Grabau, A. W., Principles of stratigraphy, p. 553, 1913.

it is known that the velocity of the current in this lowermost layer is increased at a very slow rate with an increase in the speed of the layers next above it. The velocity in the layer next to the surface of the ground probably never reaches three miles per hour. It is this comparatively inert layer, which alone comes in contact with the resting sand and first causes it to stir. As velocities much lower than this will not move sand at all, the range of variation of the velocity of the currents which impel dune sand, is most likely quite limited."

While the principle stated above is undoubtedly a modification of the general principle in the right direction, the limit of three miles an hour assumed by Udden seems to be largely a matter of guess. It may be approximately correct for those areas which came under his personal observation.

The well known effect of sand blast at the base of telephone posts in the arid west, however, would surely not be accomplished by wind of such low velocities. This erosion reaches its maximum but a few inches above the ground. Observations presented on another page (p. 180) also seem to show that sand of medium size will not be started by currents much under ten miles per hour. The writer is therefore greatly inclined to doubt the validity of such a limit in a broad desert area without vegetation, such as must obtain for the formation of any extensive eolian deposit.

If such a desert did occur, during St. Peter time, whether arid or not it probably was without vegetation because of the non-existence of land plants at that epoch. The region then, if it stood above the sea, must have been a broad plain of only very moderate relief, without vegetation, and consequently open to a much greater range of wind velocities, even at the ground surface, than those postulated by Udden. This modification would tend to coarser sands, so far as a coarse supply might be available for transport, and would therefore give grains less distinguishable from those produced by water transport.

Though the criterion of size seems, therefore, to be of less value than has been assumed, it has seemed worth while to study its application to the St. Peter and associated sandstones. In order to do this, the writer has made a rather careful study of size of grain in a number of sandstones. The results are summed up graphically in accompanying plates of curves (plates V-XII). In order that these may be thoroughly understood, the following rather detailed description of methods employed is given. The sands were first passed through a series of Tyler "Standard" screens, of the type employed so extensively in ore dressing problems. These were chosen because they are callibrated with much greater accuracy than ordinary screens. The size of grain passing any given mesh in the ordinary screens has been found to be quite variable, so that analyses made with different sets of screens are not comparable. The regular "Standard" set consists of the screens listed in the accompanying table, in which the size of opening is given for each mesh.

Table of size of opening in "Tyler Standard Screens."

Mesh.	Opening in milli-meters.
14	1.168
20	0.833
28	0.589
35	0.417
48	0.295
65	0.208
100	0.147
150	0.104
200	0.074

In all cases, the sandstones used were crushed on cardboard, with a wooden spatula, in order to avoid destroying individual grains, and thus unduly adding to the fines, pains being taken also to avoid leaving unbroken aggregates of grains, thus increasing the proportion of coarser particles beyond the proper limits. The sandstones studied were sufficiently friable so that this could be accomplished with general success. With many formations it would be impossible.

In each test, the sample was weighed, the screens nested with the coarser on top, and the separation made in a mechnical shaker, acting for fifteen minutes. This insured a careful and uniform separation of the various sizes. Each size was then weighed, the weights totaled, and the whole recomputed on the basis of 100 percent. Thus all the results are thoroughly comparable in every respect.

Each percentage thus determined represented the amount passing each sieve, and retained on the next. These were then computed into total amount passing each sieve. For example, the amount passing the 150-mesh was the amount passing the 200-mesh plus that passing the 150 and retained on the 200, and so on for each screen.

SCREEN TESTS ON SANDSTONES FROM THE JEFFERSON CITY, COTTER, AND POWELL.

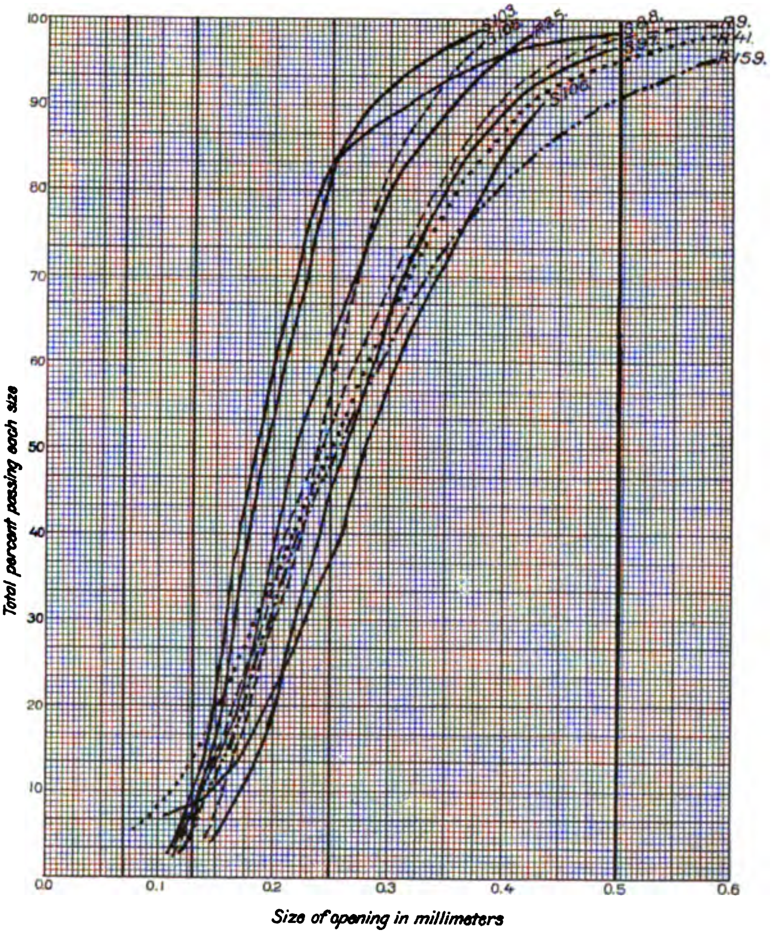

PLATE VI.

R. 9.	Sec. 31, T. 33 N., R. 11 E., Bollinger Co., Mo.
R. 25.	Sec. 18, T. 33 N., R. 10 E., Bollinger Co., Mo.
R. 41.	Sec. 14, T. 30 N., R. 9 E., Bollinger Co., Mo.
S. 88.	Sec. 32, T. 46 N., R. 6 W., Montgomery Co., Mo.
S. 97.	Sec. 20, T. 40 N., R. 6 E., Jefferson Co., Mo.
S. 103.	Sec. 7, T. 40 N., R. 6 E., Jefferson Co., Mo.
S. 105.	Sec. 7, T. 40 N., R. 6 E., Jefferson Co., Mo.
S. 106.	Sec. 29, T. 40 N., R. 6 E., Jefferson Co., Mo.
R. 159.	Sec. 22, T. 24 N., R. 1 W., Ripley Co., Mo.

Curves were next plotted, in which the horizontal coordinate represented size of opening (not screen mesh) increasing from left to right and the vertical coordinate showed the total percentage passing each screen, increasing from bottom to top. As smooth curves as possible were then drawn through the points thus obtained. These curves, (plates V-XII), familiar to engineers as mechanical analysis curves, constitute perfect pictures of the size and variation of the sands so studied, and are especially valuable for comparative purposes. A little study of such curves will show that in comparing sands the following facts are revealed.

(a) The more nearly vertical each curve, the more nearly uniform that particular sample is, as to size of grain, while the flatter the curve, the greater its range of variation.

(b) In a group of analyses, the more nearly parallel the curves, the more closely each approaches the others in degree of uniformity.

(c) The farther apart the curves are, even though parallel, the more each sample differs from the others in size, though with the same degree of uniformity, while the more nearly coincident the curves become, the more closely the sands resemble each other.

(d) The farther the curves are to the right of the page, the coarser the sand, and the farther they are to the left, the finer the sand.

(e) It is possible to tell by inspection just what percentage of any given sample lies between any given sizes of grain.

An inspection of the curves presented on plates V-XII will show at a glance that the percentage of grains in any of the sands, over 0.6 mm. in size is insignificant, except in a very few cases.

Among 12 Roubidoux samples studied, 3 had less than 1 percent retained on the 28-mesh, 3 had between 1 and 2 percent, 1 between 2 and 3 percent, one between 3 and 4 percent, and 4 had respectively 5.8, 6.3, 8.0, and 19.1 percent. The 28-mesh has an opening of 0.589 mm. Of the 12 samples, only one had any grains that would not pass the 20-mesh screen (0.833 mm.) and only 0.2 percent of it was of that size.

Among 9 sandstone samples taken from thin lenses in the Jefferson City, Cotter, and Powell dolomites, 4 have under 1 percent, 3 between 1 and 2 percent, and 2 between 2 and 3 percent that will not pass the 28-mesh (0.589 mm).

Two sandstone lenses from the Joachim dolomite show 0.2 and 0.4 percent that will not pass the 28-mesh screen. Two samples from the Potsdam of Wisconsin show 0.2 and 6.4 percent respectively that are retained on the same sieve. Of these, the coarser shows only 0.1 percent that will not pass the 20-mesh (0.833 mm.)

Of 23 St. Peter samples studied, 13 had under 1 percent retained on the 28-mesh, 5 had between 1 and 2 percent, 2 had between 2 and 3 percent, and 3 had respectively 3.5, 5.4, and 8.6 percent. Four of these had from 0.1 to 0.3 percent retained on the 20-mesh (0.833 mm.)

In regard then to the larger limit of sand grains, it seems quite apparent that the St. Peter does not differ materially from the other sands studied. Several of these are clearly marine, as shown by marine fossils at all horizons, (Roubidoux, Jefferson City, and Joachim), and on the basis of maximum size of grains there surely is nothing about the St. Peter sufficiently distinctive to warrant any assumption of an origin different from that of the others.

In all the sands tabulated above, the proportion of quartz grains in excess of 0.6 mm. is quite insignificant. There is here a suggestion of some underlying cause limiting the size of sand grains, quite independent of the agent of transportation or the distance carried, and one which will tend to render valueless, or at least relatively unimportant as a criterion of origin, any consideration of average size of grain.

What this far-reaching principle may be that tends to limit the size of sand grains in the average quartz sand is not at once apparent. It may be contended that the formations studied, being limited geographically to the central Mississippi Valley, and stratigraphically to the lower Paleozoic, have too nearly a common source and a common history to warrant their use in drawing far-reaching conclusions. It seems certain, however, that this marked similarity of even these few formations is significant.

In the samples studied, the average maximum limit in size of quartz grains seems to lie not far from 0.6 millimeter. This applies only to true quartz grains, not to complex lithic frag-

SCREEN TESTS—ROUBIDOUX SANDSTONE.

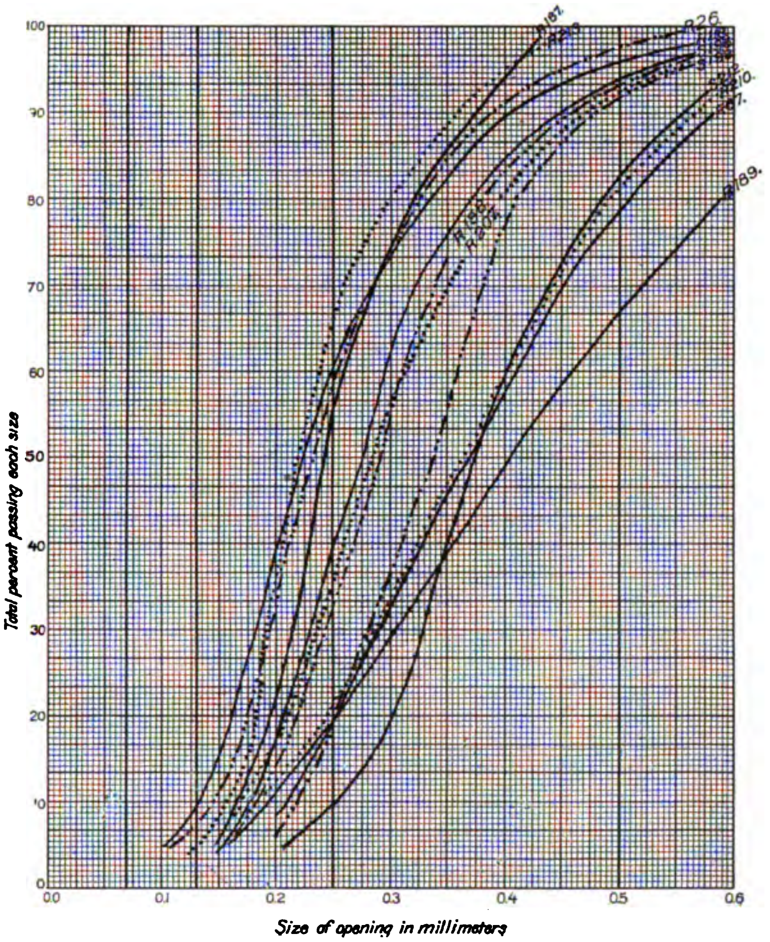

PLATE VII.

R. 26.	Sec. 10, T. 32 N., R. 9 E., Bollinger Co., Mo.
R. 67.	Sec. 4, T. 27 N., R. 6 E., Wayne Co., Mo.
R. 118.	Sec. 4, T. 24 N., R. 2 E., Ripley Co., Mo.
R. 167.	Sec. 32, T. 25 N., R. 5 W., Oregon Co., Mo.
R. 189.	Sec. 27, T. 26 N., R. 7 W., Howell Co., Mo.
S. 195.	Ava, Douglas Co., Mo.
R. 198.	Sec. 13, T. 26 N., R. 12 W., Douglas Co., Mo.
S. 199.	Meramec Springs, Phelps Co., Mo.
R. 207.	Sec. 29, T. 31 N., R. 13 W., Wright Co., Mo.
R. 210.	Sec. 9, T. 29 N., R. 4 W., Shannon Co., Mo.
S. 212.	Rolla, Phelps Co., Mo.
R. 213.	Sec. 20, T. 34 N., R. 8 W., Phelps Co., Mo.

ments, or pebbles. This limit seems to be sufficiently apparent in the several formations studied to demand some more universal explanation than the agent of transportation, and an attempt has been made to find the cause in the character of the quartz-bearing crystalline rocks, from which the quartz grains must ultimately have been derived.

Inspection of gneisses and granites reveals the fact that, while many pegmatitic phases, and coarse granites, carry quartz crystals of very large size, the prevalence of grains of one millimeter or less seems to be overwhelmingly dominating. Considered in conjunction with the fact that quite commonly the larger grains are the more fractured, and hence subject to easy fragmentation, it seems probable that after weathering, the remaining large grains would form but a small part of the whole. This condition, if true, explains at once a certain uniformity in the size of quartz grains, and places a general limit on the maximum size to be expected.

In order to partially test this theory, the writer examined a number of granites under the microscope, and actually measured the size of the quartz grains. The granites were chosen from widely separated localities, as shown in the accompanying tabulation, which gives the results of these tests in detail.

Table of sizes of quartz grains in granites, in millimeters.

Clark's Island, Maine.	Storm King Mt., New York.	George-town, Colorado.	Ilchester, Md.	Mystic Harbor, Conn.	Kingston, R. I.	New Bruns-wick.
0.3	0.2	0.4	0.1	1.0	x1.5	0.3
0.3	0.2	0.3	0.5	0.4	x1.5	0.8
0.6	x2.0	0.3	0.4	0.1	x1.0	0.9
x0.9	0.6	0.2	0.4	0.3	x1.0	0.5
0.6	0.9	0.6	0.3	0.3	x0.7	0.4
0.2	0.3	0.2	0.3	0.4	x1.2	0.6
0.2	0.4	0.3	0.2	x1.0	x1.7	0.4
0.3	0.2	0.4	1.2	0.3	0.5	0.9
0.4	0.3	0.3	x1.0	0.4	0.2	0.5
0.3	1.0	0.1	1.2	0.2	x1.5	0.3
x1.0	x0.9	0.6	x0.7	0.5	0.3	0.7
x0.8	x1.2	0.1	0.2	0.7	0.6	0.7
0.4	0.1	0.3	1.0	0.6	0.3	x1.0
0.4	0.3	0.4	0.4	0.4	0.6	1.2
0.6	0.2	0.6	0.7	0.4	x0.7	1.0
x2.0	0.1	0.3	x1.0	0.4	0.5	0.4
x0.8	0.3	0.1	0.6	0.2	2.0	0.3
0.7	0.1	0.4	0.3	0.5	0.6	0.5
0.7	0.3	0.5	1.0	0.4	0.6	0.6
0.3	0.4	x1.0	x2.0	0.3	0.5	0.7
0.4	0.8	0.5	x1.3	0.2	0.2	0.5
0.3	0.3	0.2	0.9	0.2	0.4	x1.0
x0.7	x1.0	0.2	0.8	0.7	0.3	0.8
0.2	0.8	0.7	0.3	0.1	0.2	1.0
0.2	0.4	0.6	0.3	1.0	0.7	x2.0
0.4	1.0	0.6	0.8	x1.0	0.9	0.7
0.2	0.5	0.5	1.2	x0.7	0.6	x1.2
	0.7	x1.5	x1.3	0.7	x0.9	x1.0
	0.3		x1.5	0.6	0.9	0.9
	0.2		0.9	x0.7		1.0
			1.0	0.6		0.8
			0.2	1.0		0.5
			0.5	0.8		
			x1.5	1.0		
				x1.0		
				0.3		
Av. 0.53	0.52	0.44	0.80	0.54	0.78	0.75
Max. 2.00	2.00	1.50	2.00	1.00	1.70	2.00

x-fractured grain.

Table of sizes of quartz grains in granites in millimeters.

Erze-Gebirge.	Vosges.	Erze-Gebirge.	Cape Ann, Mass.	Butte, Mont.	Chester, Mass.	Stone Mt., Ga.
1.3	x1.5	0.5	x2.1	0.7	0.5	0.4
0.2	0.3	0.4	x2.4	0.9	0.3	0.3
x2.1	x2.0	1.0	x1.2	0.6	0.2	1.4
1.2	0.2	x1.0	x1.4	0.3	0.2	x1.2
0.6	0.3	1.4	0.6	0.4	0.3	x1.0
0.8	0.2	1.2	0.5	0.4	0.2	x1.0
1.2	0.8	0.9	0.6	0.2	0.3	1.0
0.3	x2.0	x1.0	0.3	0.3	0.6	x2.0
x0.6	x0.7	x1.0	x1.8	x0.9	0.4	0.8
1.2	x0.8	0.3	x2.0	0.7	0.6	0.4
1.0	x1.2	0.5	0.4	0.4	0.9	0.7
0.8	1.0	x1.5	0.6	0.3	0.6	x1.2
0.7	0.2	0.6	0.3	0.6	0.4	x1.0
0.3	0.3	0.5	0.8	0.3	0.7	0.7
x2.0	0.7	0.9	0.4	0.3	0.3	0.5
1.2	1.3	0.6	0.6	0.2	0.4	x1.2
x2.4	0.2	0.7		0.4	0.6	0.5
x4.0	x0.8	0.6		0.6	0.3	x1.0
1.2	0.3	0.6		0.8	0.2	0.4
1.0	0.2	0.9		0.5	0.2	0.8
0.4	0.3	x2.4		0.3	0.4	0.3
1.0	0.4	0.6		0.4	0.6	0.6
0.7	0.5	0.2		0.8	0.5	0.5
x1.0	x1.4	0.3		0.3	0.6	0.4
1.0	x1.5	0.2		0.2	0.4	0.7
0.5	x1.0	1.1		0.5	0.2	x1.0
0.7	1.0	0.6		0.4	0.2	
0.5	0.4	0.6		0.5	x0.8	
0.4	0.4	0.2		0.3	0.6	
0.2	0.3	0.8		0.2		
0.7		0.6		0.9		
0.8		0.9		1.2		
x1.0		0.5		x1.4		
		0.3				
		0.4				
		0.6				
		0.8				
Av. 0.97	0.74	0.76	1.00	0.52	0.43	0.80
Max. 4.00	2.00	2.40	2.40	1.40	0.90	2.00

x-fractured grains.

In making the above measurements, a calibrated ocular micrometer was employed, together with a mechanical stage for shifting the slide with screws. Not all of any given slide was measured, but strips were examined across each, these strips chosen at random, and every quartz grain within the strip measured.

The granites were also chosen at random, except that an effort was made to get examples from numerous and widely distributed localities. Both rhyolites and pegmatites were excluded, only such rocks being chosen as were classed among the granites proper. Among those so picked, no slides were afterward excluded so that the list is believed to be reasonably representative.

While pegmatites would yield many much larger quartz grains, it is believed that quantitatively, they are so much less abundant than typical granites as not to modify greatly the size results obtained. Rhyolites, which were also excluded, would yield quartz grains smaller than the averages discovered above. Since they are actually much more abundant than pegmatites, their inclusion would tend to reduce, rather than increase, the average size shown above.

Out of 420 grains actually measured, only 161 were over 0.6 mm. in diameter. Of these larger grains, those marked in the table by a star, 79 in number, were so badly broken that they would not yield sand grains over 0.6 mm. in diameter, leaving only 82, or approximately 20 percent, that would give grains larger than 0.6 mm.

In this same list, only 101 are one millimeter or over, in diameter, and of these, 63 are badly broken, leaving only 38, or about 9 percent that would yield grains over one millimeter in diameter.

Two other factors would also tend to further reduce this percentage. One of them is that no grains under 0.1 millimeter in diameter were measured at all, and another is that without much doubt, some at least, of the apparently unfractured grains, actually possessed incipient fracture which would allow them to go to pieces under weathering processes.

On the other hand, only a few of the grains in any thin section show their maximum diameter, and the figures thus obatined will to that degree be too small. It is difficult to estimate how im-

SCREEN TESTS—ST. PETER SANDSTONE.

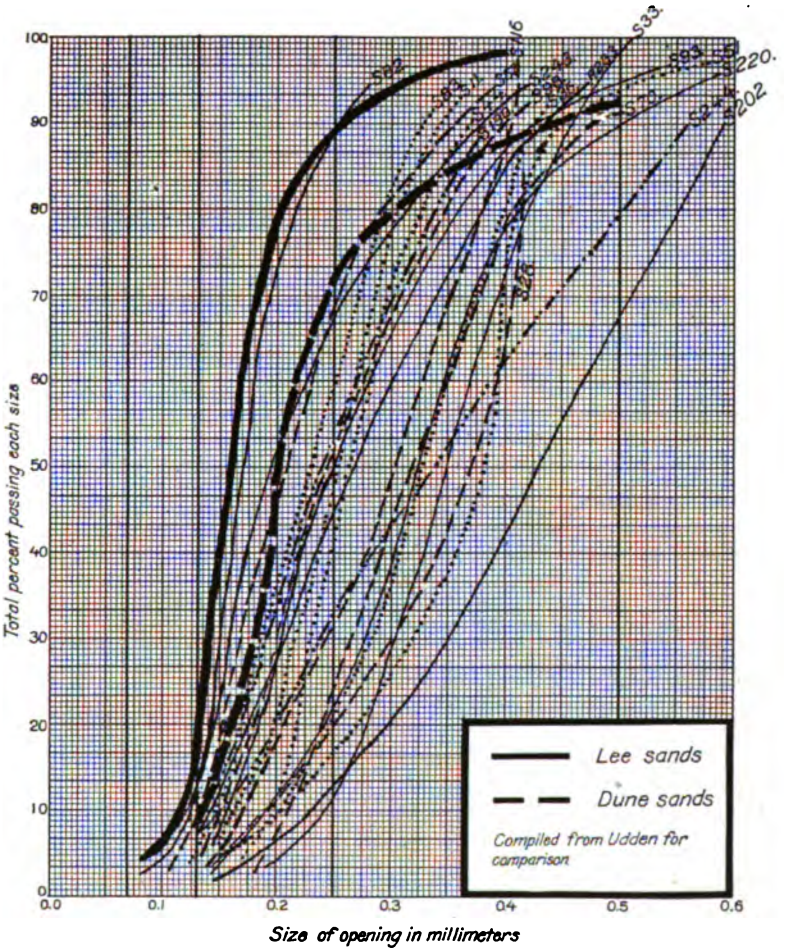

PLATE VIII.

S. 11. Sec. 5, T. 34 N., R. 11 E., Perry Co., Mo.
S. 28. Sec. 19, T. 30 N., R. 13 E., Cape Girardeau Co., Mo.
S. 33. Pittsburgh Plate Glass Company's Quarry, Crystal City, Mo.
S. 35. Pittsburgh Plate Glass Company's Quarry, Crystal City, Mo.
S. 44. Sec. 22, T. 44 N., R. 2 E., St. Charles Co., Mo.
S. 51. Tavern Rock Sand Company's Quarry, St. Louis Co., Mo.
S. 57. Sec. 18, T. 42 N., R. 4 E., Jefferson Co., Mo.
S. 70. Sec. 2, T. 49 N., R. 2 E., Lincoln Co., Mo.
S. 82. Sec. 32, T. 46 N., R. 2 W., Warren Co., Mo.
S. 83. Sec. 1, T. 45 N., R. 3 W., Warren Co., Mo.
S. 93. Sec. 36, T. 47 N., R. 6 W., Montgomery Co., Mo.
S. 98. Sec. 20, T. 40 N., R. 6 E., Jefferson Co., Mo.
S. 116. Sec. 10, T. 38 N., R. 7 E., Ste. Genevieve Co., Mo.
S. 190. Pacific Glass Sand Company's Quarry, Pacific, Mo.
S. 202. St. Peter Sandstone, Ottawa, Ill.
S. 220. Everton Sandstone, Sec. 20, T. 40 N., R. 6 E., Jefferson Co., Mo.
R. 233. St. Peter Sandstone, Northeast Iowa, furnished by A. C. Trowbridge.
S. 243. St. Peter Sandstone, River Falls, Wis.
S. 244. St. Peter Sandstone, LaSalle, Ill., furnished by J. Bridge.

portant this consideration actually is. Since, however, in the above determinations of sizes of grains, the extreme limits, including their irregular salients, were carefully measured and since these would be the first to wear away, the importance of the possibility of under-estimates is somewhat reduced.

Since most sand grains are ultimately derived from igneous rocks, the measurements, while not extensive enough to justify close comparison of percentages, are surely sufficiently conclusive to indicate the limiting maximum size of grains in pure quartz sands. A comparison of these figures with the sizes of grain already shown for the St. Peter (pp. 157-158) suggests that, aside from removing the angles, and rounding the grains, relatively little diminution in size has occurred, in the quartz particles, during the transfer from granite to sandstone. As might be expected, the wearing goes on much more slowly after the corners are rounded off.

Of course, the more nearly uniform, and uniformly small, the size of grains in the source of supply, the less can size and uniformity be depended upon as a criterion in studying the agencies that transported and deposited a given sand.

Having shown that the maximum size limit can probably not be used as a criterion of origin; and having shown also, and that conclusively, that the maximum size in the St. Peter is almost identical with that in several marine sandstones, and that therefore, it can certainly not be used as an argument for any different origin of the St. Peter, it remains to consider the average size of grains.

As already pointed out, Udden shows 46 analyses of wind-driven sand, in which over 50 percent of the sample lies between the sizes 1–8 to 1–4 mm., and suggests that a dominance of this size points to eolian origin. Most of his dune sands seem to have been derived, however, from sands already moderately fine and well-assorted. And it is to be expected that another working over by any agent, wind or water, would render them finer and still better sorted. The value of the criterion has already been called into question, the importance of several modifications being pointed out. Nevertheless, it may be well to compare Uddens results with screen tests made by the writer on Paleozoic sandstone formations. A glance at Plate VII shows that of 12 samples of the Roubidoux plotted, only 4 have

50 percent or more lying between 1–8 and 1–4 mm., the other 8 having their maximum in the coarser grade. In fact, 5 of them have under 20 percent falling within the former limits. The Roubidoux is known to be marine, though of course, it would be impossible to prove that its grains had never been wind-blown.

Of 9 samples of the sandstone lenses from the Jefferson City, Cotter, and Powell (Plate VI), marine formations, 4 have 56 percent or over between the limits of 1-8 and 1-4 mm., two have 44 and 46 percent within those limits, and 3 have maxima of 46, 54, and 60 percent respectively in the larger grade. The Roubidoux and Jefferson City formations are closely related in origin, both being marine, the latter above the former and with the more limestone, suggesting the clearer seas, probably more distant from land, or with a lower and less rapidly eroding land mass contributing sediment. In consonance with this idea, the Jefferson City has the finer sand, well within the sizes said by Udden to be most characteristic of wind work.

Two sandstones from the Potsdam (Plate V.) have about 33 and 50 percent respectively between 1–8 and 1–4 mm. While the Potsdam samples are too few to warrant any general conclusions, it is interesting to note that they are not dissimilar from the St. Peter, which is believed to be derived from Potsdam sources.

Of 20 St. Peter curves (Plate VIII), 6 show maxima of from 47 to 79 percent within the limits above set, the large majority being much coarser, seven of the 20 showing under 30 percent within the sizes of 1–8 to 1–4 mm.

It is not the writer's purpose to disparage the value of a criterion, and then use it as evidence to prove a point. He has, however, called into question the validity of the widely used argument, and has shown by a series of comparisons, that the criterion, even if true, does not prove, concerning the St. Peter sandstone, the thing it has been assumed to prove.

In other words, whether the principle involved in the criterion is valid or not, the St. Peter is seen to be coarser than the sizes suggested by Udden for wind-driven sand and entirely comparable to sizes found in several marine formations in the same region. Not only, therefore, does the criterion appear to be invalid, but in any case, it clearly does not apply to the St. Peter sandstone.

SCREEN TESTS—JOACHIM SANDSTONE LENSES.

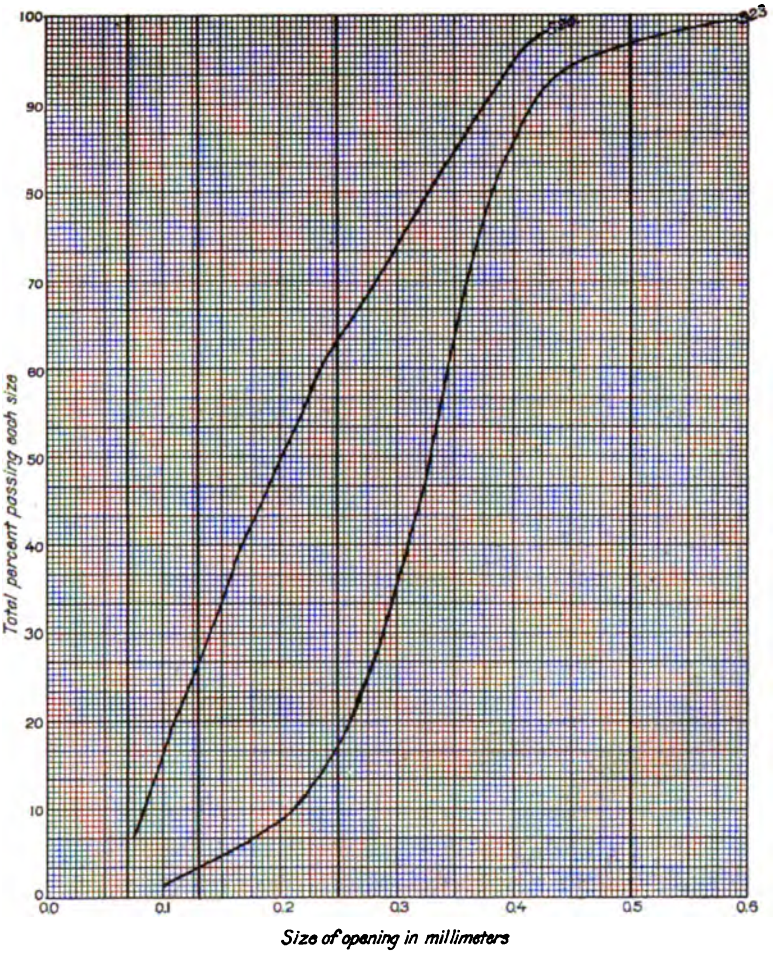

PLATE IX.

S. 20. Sec. 5, T. 31 N., R. 12 E., Cape Girardeau Co., Mo.

S. 23. Sec. 17, T. 32 N., R. 12 E., Cape Girardeau Co., Mo.

The writer would not presume to say that the comparisons cited above prove the marine origin of the St. Peter; but most emphatically, they do not prove its eolian origin.

Summary.—Udden, followed by others, has attempted to show that wind-blown sands are fine, and conversely, that fineness of grains suggests eolion origin. He considers a dominance of the size between 1–8 and 1–4 mm. to be most characteristic of wind-drifted sand. The writer has pointed out the importance of a consideration of the size of material in the supply ground, and suggests that an apparent maximum lying near 0.6 mm. for quartz grains may be related to the size of quartz crystals in crystalline sources. He also points out the fact that the greater the distance transported, the finer the grains, in any given sand. He also questions Udden's limit of 3 miles per hour for bottom air currents, at least over large desert areas. Stated concisely with the necessary modifications, Udden's principle might read: a wind-drifted sand will usually be of smaller grains than a water-borne sand which has been derived from the same source, and transported an equal distance; and the farther the sand is removed from the source, the more noticeable will be the difference. It will be nearly impossible, however, on the basis of size and sorting, to tell whether fineness and perfect assortment mean wind transportation for a given distance, or water transportation for a much greater distance; or whether it may not even mean the working over by waves, for a very long time, without being transported such long distances. In view of these modifications, it is suggested that size is probably of but little value in determining the origin of the sand, unless many other factors are evaluated, which are usually not decipherable.

Comparisons are also made between the size of grain of the St. Peter and other sands, in which it is shown that the St. Peter is coarser than Udden's suggested limits for wind-blown material, and is entirely comparable in sizes with several marine Paleozoic formations in the same region. It is not presumed to show the marine origin of the St. Peter, from these facts alone, but it is insisted that the evidence of size cannot, by any stretch of fancy, be made to favor eolian origin of the formation.

Uniformity of grain in the St. Peter.

The term uniformity may apply to any characteristic, physical or chemical. Its chemical application has already been considered in the discussion of composition. Uniformity of thickness will be discussed in a later paragraph. In this place, only uniformity of size of grains will be considered.

The term uniformity, even when applied to size, may be understood in two distinct senses. Uniformity may apply to the range in size of grains within a single sample. This is the sense in which it is invariably used by engineers. In another sense it refers to comparisons of sizes in different localities. In the usual descriptions of the St. Peter, in which uniformity has been repeatedly emphasized, it is not always clear in which sense the word is used. In the one sense, or the other, or both, uniformity has always been assumed to be characteristic of eolian sands, thus being placed in the rank of important criteria.[21]

The discussion of the subject, then, naturally falls into two topics, the validity of uniformity as a criterion of eolian sand and the consideration of the uniformity of the St. Peter sandstone.

The fact that the fine dust particles, which can be lifted at all by the air, are raised into currents the velocity of which is so vastly greater than the usual water currents seems to justify the conclusion that wind is a more efficient agent than water for the rapid and complete removal of the very fine constituents of a sand. This applies to clay particles, minute mica flakes, and very finely powdered silica. Studies made by Udden[22] and confirmed by others, seem to indicate that such wind-floated material will be chiefly under 0.1 mm. in diameter.

It is to be presumed, then, that wind-drifted sands would be largely lacking in this very fine material. Again, however, we must not lose sight of the importance of the length of transport, or more accurately stated, the length of time the sand has been under the influence of wind-drift. A sand worked over for long by water may, even if from the same source, be purer than one only recently under the influence of wind transport. Nor must the character of the source be ignored. A sand derived from a source nearly free from clay, even if but slightly worked over by water, may contain less of the finer material than one subjected to considerable wind work if its source contains much clay. This point is of particular significance, when we recall that the St. Peter is probably derived from the Potsdam, a formation itself moderately free from finer particles.

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[21] Udden, J. A., The mechanical composition of wind deposits, Augustana Library Publication, 1898.

[22] Udden, J. A., loc. cit.

A sand, however, may be uniformly rather free from finer particles, and still have a considerable range for possible variation in the individual sample. In other words, the grains present may fall largely within a small range of size, the other sizes present being represented by inconsiderable quantities, or they may be well distributed through all the sizes present. So far as the writer is aware, there is no valid reason for assuming that this type of uniformity should be greater in a wind-blown sand than in a marine one. It seems to be self-evident that the same law of ratio of velocity to transportation capacity (T varies as V^6) holds for both media. And since the variations in velocity of the wind are presumably much greater even at the ground surface in a barren area, than are those of currents and waves in the shallow seas; and since these variations range through wide limits of velocity in a very short time, it is possible that locally wind-blown sand might show a very high degree of sorting, while on the average it would be no more uniform than a marine deposit.

Similarly, no valid explanation seems to have been offered for the assumed greater uniformity, over large areas, of wind-blown sands as contrasted with water-laid ones. The writer is inclined, for reasons just cited, to believe that the difference, if there is any, will be in the direction of greater uniformity for the marine deposits, since they are subject to less range of velocities. One might actually expect considerable variations in size of grain on the windward and leeward sides of dunes, and in a stratification of well and poorly assorted layers, usually very thin. Such structural features, both of stratification and cross-bedding, emphasized by textural differences, should be more marked in wind-laid beds than in marine. It seems very doubtful, however, whether this difference is one which can be used at all as a criterion, in a study of the origin of the sandstones. No such features were detected in the St. Peter. Such textural stratification and cross-bedding, however, might be largely destroyed by subsequent wave modification, even in a wind-drifted deposit.

Heretofore, the matter of uniformity has rested largely upon the judgment of the observer. Engineers have, however, devised quantitative methods of comparing the uniformity of various sands for engineering purposes, and these are here applied, apparently for the first time, to the problem of origin of the St. Peter. The chief standard of comparison known as the coefficient of uniformity, is defined as

> "The ratio of the size of grain which has 60 percent of the sample finer than itself to the size which has 10 percent finer than itself."[23]

It is the ratio of variation of size of the most abundant portion of the sand, excluding the extremes on either end. The writer[24] has further explained the meaning of this factor as follows:

> "In a sand, if just 10 percent were finer than 1mm. and just 60 percent finer than 2mm., the uniformity coefficient would be 2. In other words, 50 percent of the sample lies between 1 mm. and 2 mm. in diameter. Similarly, if 10 percent of the sample were finer than 3 mm. and 60 percent finer than 6mm., the uniformity coefficient would again be 2, though the latter sand would be three times as coarse as the former. Thus it will be seen that the uniformity coefficient does not necessarily indicate the absolute coarseness or fineness of a sand. It merely expresses a ratio of variation of size of grain. A sand with a coefficient of 5 means that 50 percent of that sand has a variation in size of grain represented by the ratio of 1:5. A uniformity coefficient of 1, which is almost an impossiblity, would mean that 50 percent of the sand was uniform in size, with 10 percent smaller and 40 percent larger than this size. The smaller the uniformity coefficient, the more uniform the grain of the sand; the larger the uniformity coefficient, the less uniform the grain of the sand."

With uniformity coefficient is also much used by engineers another term, effective size, which is defined[25] as a size "such that 10 percent of the material is of smaller grains, and 90 percent is of larger grains than the size given." That is, if 10 percent of a sand passed a screen with openings of 0.2 mm., and 90 percent were retained on the screen, the effective size would be 0.2 mm. Since the size at the 10 percent point is also used in defining uniformity coefficient, these two factors rather closely describe the size and uniformity of any sand.

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[23] Condra, G. E., Sand and gravel resources and industries of Nebraska; Neb. Geol. Survey, vol. III, pt. I, p. 30, 1908.

[24] Dake, C. L., The sand and gravel resources of Missouri; Mo. Bur. Geol. and Mines, vol. XV, p. 14, 1918.

[25] Condra, G. E., op. cit., p. 31.

SCREEN TESTS ON OTHER SANDSTONES.

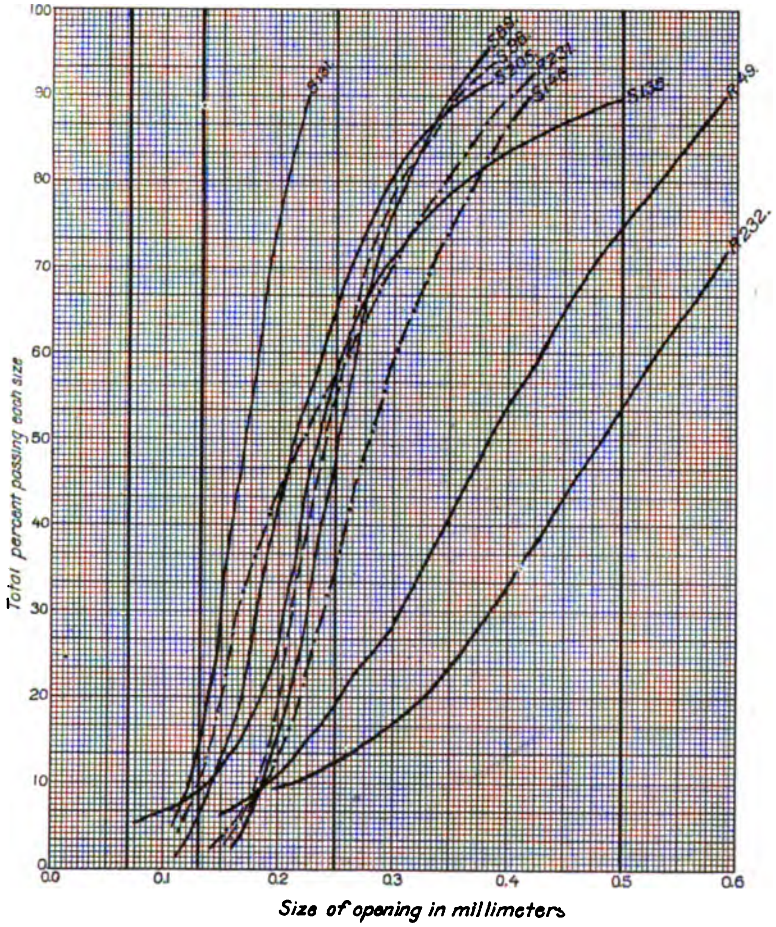

PLATE X.

R. 49. Gunter sandstone, Missouri.
S. 89. Pennsylvanian sandstone, Montgomery Co., Mo.
S. 96. Pennsylvanian sandstone, Montgomery Co., Mo.
S. 131. Chester sandstone, Perry Co., Mo.
S. 135. Aux Vases sandstone, Perry Co., Mo.
S. 146. Commerce (Tertiary?) sandstone, Commerce, Mo.
S. 205. Pennsylvanian sandstone, Arcola, Mo.
R. 231. Pennsylvanian sandstone, Sullivan, Mo.
R. 232. Jordan sandstone, northeast Iowa. Furnished by A. C. Trowbridge.

These figures are usually obtained graphically, from the curves representing mechanical analyses, such as are described in an earlier paragraph (p. 157).

In the following table are listed the effective sizes and uniformity coefficients for a large number of tests made by the writer for this particular study.

Table of effective size and uniformity coefficient.

St. Peter.		Roubidoux.		Jefferson City Group.	
E. S. in mm.	U. C.	E. S. in mm.	U. C.	E. S. in mm.	U. C.
.145	2.10	.135	1.93	.140	2.07
.240	1.95	.150	1.60	.135	2.00
.150	2.60	.180	1.75	.130	1.85
.120	1.87	.165	1.60	.110	2.54
.150	1.80	.215	1.90	.145	2.10
.200	1.75	.130	1.95	.180	1.60
.170	1.97	.185	2.19	.130	1.54
.160	1.75	.195	2.35	.140	1.50
.150	1.83	.175	1.83	.130	1.82
.155	2.06	.175	1.71	.110	2.27
.195	1.43	.220	1.54		
.130	1.73	.250	1.60		
.155	1.67				
.150	1.83				
.200	1.95				
.190	1.86				
.190	1.95				

In the report on the "Sand and Gravel Resources of Missouri"[26] the writer summed up conclusions there presented by saying:

> "It will be seen that the effective size of the St. Peter sand samples tested ranges between 0.12 mm. and 0.25 mm. with an average of 0.154 mm. for 26 specimens. These specimens are fairly representative of the entire area of outcrop in this State (Missouri). Eighteen other samples of local sandstones, representing eight different formations ranging in age from Cambrian to Tertiary show effective size varying between 0.10 mm. and 0.28 mm., with an average of 0.158mm. The difference is entirely inappreciable either as to average or extreme range.
>
> "In uniformity coefficient, the same 26 samples of St. Peter give a maximum of 2.31 and a minimum of 1.43, with an average of 1.84. The eighteen samples of other sandstones show a maximum of 2.27 (excluding No. 217, which is really a conglomerate), a minimum of 1.39, and an average of 1.65. The latter com-

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[26] Dake, C. L., op. cit., p. 127.

parison shows that the St. Peter sandstone has a greater range of size, and averages less uniform than the other formations sampled.

"This should be sufficient to show that the factor of uniformity has been heretofore greatly overestimated in describing the St. Peter formation."

The results quoted above were derived from tests made for commercial purposes. Since then the writer has made many other tests, with more accurate sets of screens, and these are the ones tabulated above.

Of 17 determinations of effective size (all new) made on the St. Peter, the maximum is 0.240 mm., the minimum is 0.120 mm., and the average 0.167 mm. The extremes are essentially in accord with those previously published. The average seems to be somewhat larger, but the difference is not great, being 0.154 mm. for the first lot, and 0.167 mm. for the last. For the 12 samples of the Roubidoux, the effective size ranges from a minimum of 0.13 mm. to a maximum of 0.250 mm. and averages 0.181 mm., which is essentially the range noted in the St. Peter, though the average is slightly larger in the Roubidoux, the average effective size of which exceeds that of the St. Peter by less than 0.03 mm. Such a difference can hardly be assumed to be significant.

The effective size of the ten samples of the Jefferson City Group ranges from 0.110 to 0.180 mm. and averages 0.140 mm., which in range is more uniform than the St. Peter, and actually averages finer by about as much as the Roubidoux is larger. Two samples of the Potsdam show effective size of 0.160 mm. and 0.170 mm., two of the Joachim, 0.210 mm. and 0.090 mm. The latter is smaller than any St. Peter noted. The Joachim, Jefferson City, and Roubidoux, which are all marine, are certainly comparable to the St. Peter.

Three samples of the Pennsylvanian and one of the Tertiary show respectively 0.180 mm., 0.180 mm., and 0.130 mm., and 0.160 mm. The comparison, in this case, is in part invalidated by the fact that these four sands probably contain considerable material contributed by the St. Peter.

Beach sands from Florida and New Jersey show effective size of 0.200 mm. and 0.370 mm., respectively, the latter being the coarsest sand studied. Dune sands from New Mexico and Michigan City, Indiana, showed respectively 0.170 mm. and 0.170 mm.

The degree of uniformity at the 10 percent line (effective size) is certainly comparable in all respects with the other sands studied. Similar comparisons were made for the coefficient.

Of the 17 determinations of the St. Peter tabulated, the minimum coefficient of uniformity is 1.43 and the maximum 2.60, the average being 1.89. These figures are also entirely comparable with the St. Peter determinations presented in a previous paper, and referred to on p. 169, the minimum there being 1.43, the maximum 2.31, and the average 1.84. The differences are so slight as to be practically negligible.

For 12 samples, the Roubidoux coefficient shows a maximum of 2.35, a minimum of 1.54 and an average of 1.83, results remarkably similar to those of the St. Peter. It will be noted that no sample of the Roubidoux tested showed quite the degree of uniformity of one St. Peter sample, with a coefficient of 1.43. This is the only sample, however, to show greater uniformity than was shown by the Roubidoux sands, and on the other hand, one St. Peter sample with a coefficient of 2.60 showed a less degree of uniformity than any Roubidoux tested, while the average is almost identical, being slightly in favor of the Roubidoux. However, the differences are so slight as to be entirely insignificant, falling easily within the range of variations inherent in the methods of analysis.

Ten samples of the Jefferson City Group show a maximum of 2.54, a minimum of 1.50, and an average of 1.93. The extreme ranges are within those shown by the St. Peter, the average being however, slightly less uniform. Still the differences are such as to be entirely insignificant.

The Roubidoux and the Jefferson City, both of which are marine, show a degree of uniformity so close to that of the St. Peter that the comparison is striking.

Two samples of the Joachim show 1.60 and 2.66, and two of the Potsdam, from Wisconsin, 1.63 and 1.94. Three of the Pennsylvanian and one of the Tertiary, which probably contain admixtures of original St. Peter grains, show 1.44, 1.44, 1.85, and 1.49 respectively. New Jersey and Florida beach sands show respectively 1.50 and 1.70, and Indiana and New Mexico dune sands 1.47 and 1.50 respectively.

The results reviewed above are also graphically presented by the curves on plates V.-XII. It must be remembered that the more nearly vertical the curves, the more uniform each sample; the more closely crowded the curves, the more nearly uniform the average of the several samples; and the farther to the right, the coarser the sand. Comparing the Roubidoux (plate VII) with the St. Peter curves (plate VIII), it will be seen that there is essential correspondence in every particular. If the two sets of curves were superimposed, one upon the other, the Roubidoux would coincide with remarkable exactness with the St. Peter. The same will be true for the Jefferson City curves (plate VI) and for those of the Joachim (plate IX). The two Potsdam curves (plate V) show a similar situation. The same is true for the curves (plate X), showing "other sandstones", the Jordan being the only one to fall notably outside the St. Peter range. It is, of course, not possible to say just how characteristic this single sample of Jordan sandstone is. The criticism has been made that the Roubidoux and Jefferson City are more local, and that the St. Peter is more uniform over large areas. To offset this, it must be borne in mind that they also represent a greater stratigraphic range, and if the figures for the Potsdam are considered, the geographical area is essentially as large for the other sandstones combined, as for the St. Peter.

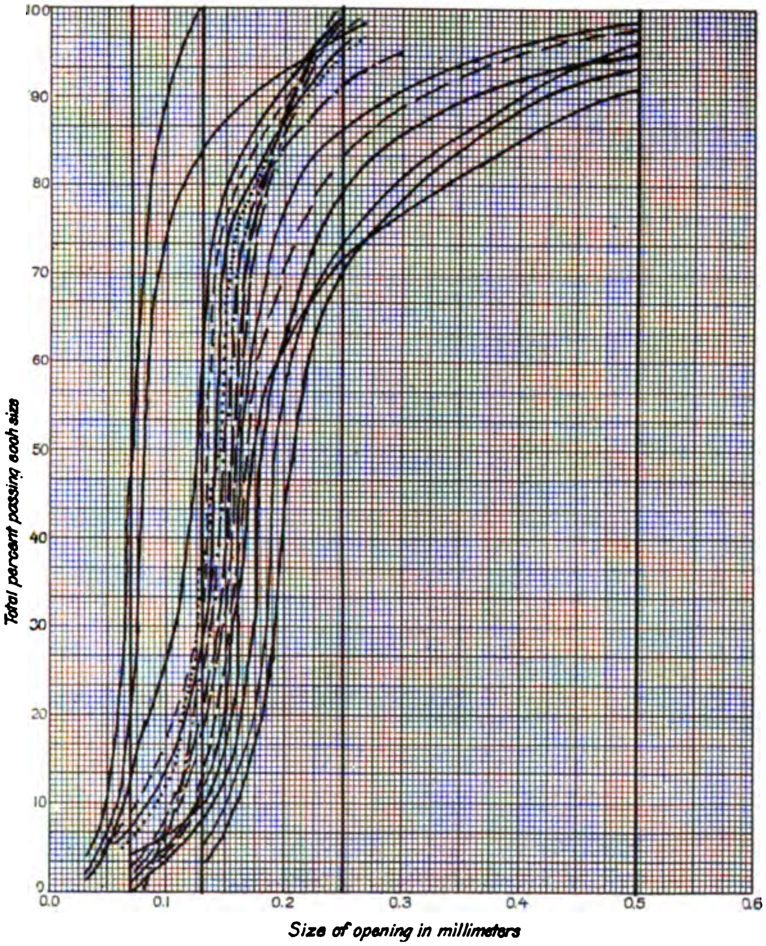
Enough data have been presented to show very positively that the feature of uniformity in size of grain in the St. Peter sandstone has been greatly over-emphasized as compared with other early Paleozoic sandstones of the same region. In fact, the St. Peter is no more uniform in the size of grain than most other *pure quartz* sandstones, and is practically identical with that of the Roubidoux and the Jefferson City, both older marine beds lying below the unconformity at the base of the St. Peter.

This statement applies both to the uniformity in single samples, and to the uniformity over large areas, the areas of Roubidoux and Jefferson City studied being in general the same as those over which the St. Peter was sampled, the bulk of all the samples coming from Missouri. The above facts are also graphically shown in the photomicrographs of various sands (plates XIII-XX) in which the St. Peter is clearly seen to have as great a range in size as the others.

The evidence presented above is such as entirely to destroy the value of supposed superior uniformity as a criterion for the eolian deposition of the St. Peter.

SCREEN TESTS ON WIND-BLOWN "LEE SANDS."

Compiled from Udden's data.



Another application of the principle of uniformity is Udden's[27] so-called law for eolian sands, which he states as follows:

> "The admixtures arrange themselves in two series decreasing on either side of the maximum. The coarse admixtures form a less rapidly decreasing series than the fine, the former extending over five grades in the general average, and the latter over only three grades."

This statement has been interpreted in various ways. Dr. Galloway has stated it essentially as follows: If the next larger amount is on the coarser side, the sand is probably eolian, if, on the finer side, probably water-laid. A better interpretation would probably be, if the total coarser than the maximum grade[28] is greater than the total finer than the maximum grade, the sand is more probably eolian. Since a considerable part of the material finer than the grade referred to as fine sand (1/8 to 1/4 mm.) is within the range of the lifting power of the wind, this is simply another method of stating the supposition that the excessively fine material is more apt to be completely removed by wind than by water, a principle discussed at length in earlier paragraphs.

A careful analysis of the supposed law brings out several very interesting facts. Among these, not the least striking is the effect produced by varying the size of the grades chosen. The three most abundant grades found by Udden in his sands are, by inspection of his graphs, seen to be very fine sand (1/16 to 1/8 mm.), fine sand (1/8 to 1/4 mm.), and medium sand (1/4 to 1/2 mm.). For purposes of study, vertical lines have been drawn at these sizes, through the curves on plates V-XII. Studying the Roubidoux curves, it will be seen that for most of them the maximum is in the size between ¼ and ½ mm. Taking as a good example curve S.212, it will be noted that over 70 percent of the sample is of this size, with 10 percent smaller, and more than 15 percent larger, which, according to the law, would suggest eolian origin.

Supposing, however, the sizes of the grades (group of grains of a given size) had been chosen with slightly different limits, making the fine sand from 0.15 to 0.30 mm., and the medium grade from 0.30 to 0.55 mm., the maximum percentage would still lie within the medium size, but now with 20 percent smaller and only 10 percent larger. This involves but a very slight shift in the size of grade, but reverses the percentages larger and smaller than the maximum grade. It is not apparent that the size of grades used by Udden has any relation whatever to the origin or character of sands in general, or to any process involved in the wearing of the sand grains, or at least the only such relationship is that the lower limit of his fine sand lies close to the limit of competency of the average wind to lift grains, so that a considerable part of the material finer than that size is easily blown away.

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[27] Udden, J. A., The mechanical composition of wind deposits; Augustana Library Publication, No. 1, pp. 22-23, 1898.

[28] A grade is the total amount of sand of a given size.

If the maximum percentage lay in the medium sand (¼ to ½ mm.) farther from the size easily floated by the wind, it is quite probable that more of the samples would show the greater percentage on the side of the finer grains. In Udden's[29] table of rolling drift sand, where larger sizes prevail, of 11 samples listed, 7 have the next largest percentage on the side of finer grains, and 9 of them have a larger total on the fine than on the coarse side. This explanation is still further verified by reference to the writer's analyses. An inspection of the Roubidoux curves (plate VII) shows that of the four which have the maximum grade of size between 1/8 and 1/4 mm., all have larger percentages on the coarser than on the finer side, which under the application of the law, might suggest eolian origin, while of the 8 that have the maximum percentage between ¼ and ½ mm., 4 clearly have the highest percentage on the finer side, 3 have it about equally divided, and only 1 (R. 189) has it definitely on the coarser side. An inspection of the St. Peter curves (plate VIII) shows an entirely comparable situation.

It seems certain, then, that two factors, neither of which is the origin of the sand, control whether or not the greatest proportion of material lies on the coarse or fine side of the maximum. One of these is the limits of size chosen for the different grades, and the other is the average coarseness or fineness of the sand as a whole. It is believed that these two factors, and not the distinction between wind-blown and water-laid sands, control the relationship pointed out; and that, therefore, we are no longer justified in considering it as a criterion for deciding the origin of sands.

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[29] Udden, J. A., op. cit. p. 10.

Nevertheless, it will be of interest perhaps, to study the sandstones already described in this paper, in the light of the supposed law, to see what results can be secured. To make as close a comparison as possible with Udden's law, the sandtsones will be described in terms of the same sizes he used.

Reference to the Roubidoux curves (plate VII) shows, of 12 samples, 5 that have the largest percentage on the coarse side of the maximum, 4 on the fine side, and 3 nearly equal. The Jefferson City Group, out of 9 curves, shows 5 with the larger percentage clearly on the coarser side, 3 on the finer side, and 1 nearly equal. By the application of the law, these sands would be more or less indeterminate, with the balance in favor of eolian origin. While it would of course be difficult, probably impossible, to prove that they had never been wind-blown, the field evidence is convincing that they were laid down as typical marine formations.

Studying now the 20 St. Peter curves (plate VIII), 12 show the largest percent on the finer side, 5 on the coarser side, and 3 are about evenly divided. Applying the law, this would suggest the water-laid origin of the St. Peter. It is not to be considered, however, that the writer presents this as any evidence whatever of the marine origin of the St. Peter sandstone.

The above facts show, first that the criterion itself is probably of little or no value, and second, that whatever its value, it certainly does not point to eolian origin of the St. Peter sandstone. In justice to Udden, however, it must be said that in later work he has admitted that certain processes of water work can develop similar sorting which cannot be distinguished from eolian action.[30]

Still another principle laid down by Udden[31] is "that the chief ingredient in water deposits contains about 5 percent less than it usually does in wind deposits." This is merely another aspect of uniformity.

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[30] Udden, J. A., Mechanical composition of clastic sediments; Bull. Geol. Soc. America, vol. 25, 1914, p. 738.

[31] Udden, J. A., op. cit. p. 741.

Comparisons on this basis of the analyses made by the writer are given below:

Jefferson City Group (9 samples).
Maxima in fine sand, 44, 46, 56, 57, 76, 79 percent.
Maxima in medium sands, 46, 54, 60 percent.
Average 57.5 percent.

Roubidoux (12 samples).
Maxima in fine sand, 49, 50, 50 and 61 percent.
Maxima in medium sand, 47, 54, 56, 60, 60, 72, 72, 74 percent.
Average 58.8 percent.

St. Peter (21 samples).
Maxima in fine sand, 47, 47, 60, 60, 61, 79 percent.
Maxima in medium sand, 46, 48, 50, 51, 54, 54, 55, 55, 67, 67, 70, 71, 76, 77, 86 percent.
Average 60.7 percent.

Comparing the three sandstones above listed, it will be noted that the range of percentages in the maxima are very similar, except for a single remarkably large maximum in the St. Peter group.

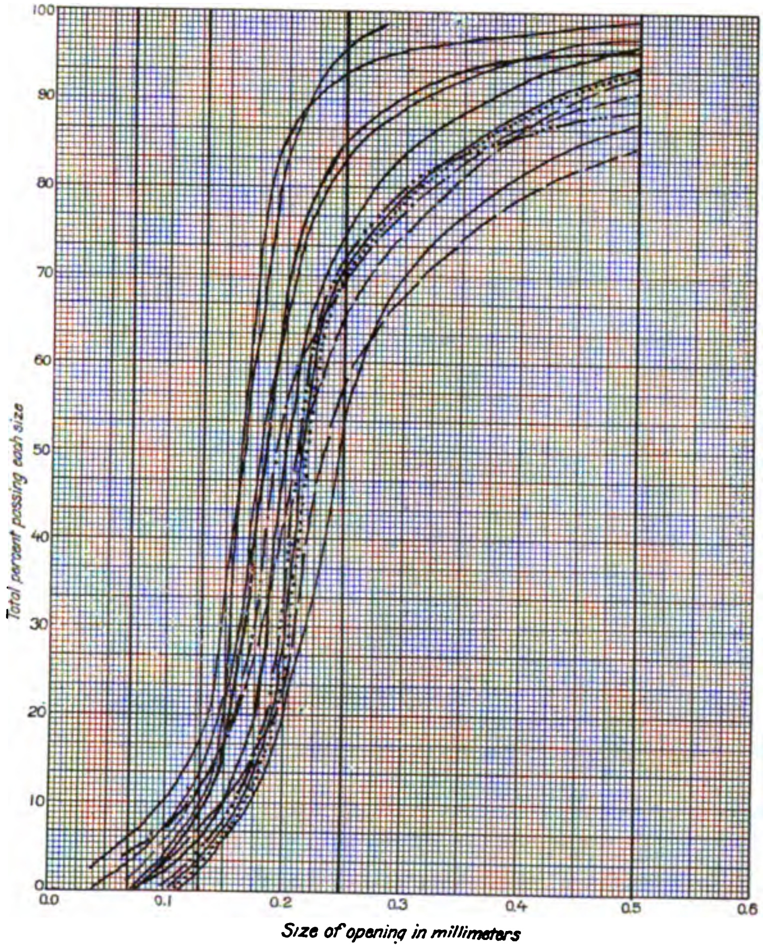
The chief ingredient averages 57.5 percent in the Jefferson City, 58.8 percent in the Roubidoux, and 60.7 percent in the St. Peter. This seems to indicate slightly greater uniformity of the St. Peter than of the others as contrasted with lesser uniformity indicated by the comparison of the coefficients. The apparent anomaly may perhaps be due to the fact that the uniformity coefficient measures the range in sizes only between the 10 percent and 60 percent lines, while the averages given above reach into the finer and coarser grades, and hence allow a possibility of greater variation.

The averages, however, are not as significant as might appear. The total range between 57.5 percent, the lowest average, and 60.7 percent, the highest, is only 3.2 percent. It will also be noted that the difference between the marine Jefferson City Group, and the marine Roubidoux, 1.3 percent, is almost as great as that between the Roubidoux and the St. Peter, 1.9 percent. Surely no important conclusions can be based on so small an average difference.

The following argument illustrates the danger of using so slight a variation as a basis for broad generalizations. If the one extreme sample of the St. Peter, with 86 percent in the maximum grade, be rejected, the average for that formation drops to 59.5 percent, a decrease of 1.2 percent. If, a single

SCREEN TESTS ON DUNE SANDS.

Compiled from Udden's data.



unusual, or possibly incorrect, result can change the average by a figure nearly as large as the supposedly significant difference, it is clear that important conclusions should not be based on such small variations.

Summary.—The writer has shown, concerning uniformity of grain, first that it is probably not a valid criterion for eolian sands; and secondly that whatever its value it does not apply to the St. Peter, which is actually not more uniform than other Paleozoic sands of the same region, known to be of marine origin. While the St. Peter is actually a remarkable sandstone, both in purity and uniformity as compared with the average of all rocks classed as sandstones, it is not remarkably different from other sandstones of the same region, derived at about the same geologic time, and apparently not greatly different from *pure quartz* sands in other regions. It is then not a matter of explaining the St. Peter alone, but of evaluating the paleogeographic conditions of the entire early Paleozoic of the central United States.

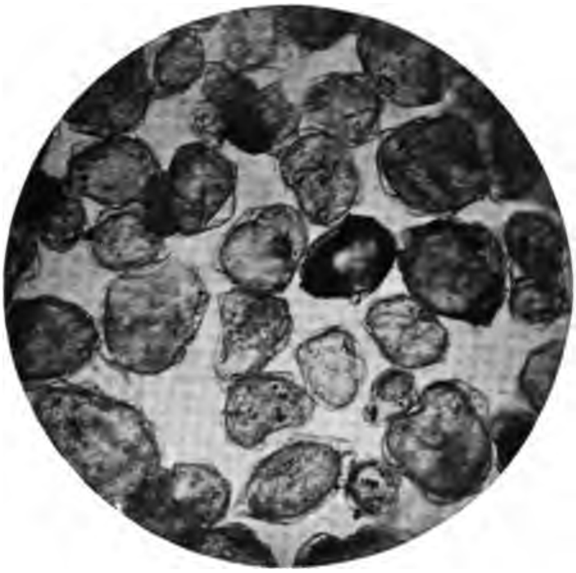
Again, the law of Udden that the "coarse admixtures form a less rapidly decreasing series than the fine" has been shown to be dependent on the size of grades chosen and on the general coarseness of the sand studied, and is not a valid criterion of wind-blown origin. If the wind-blown sands are fine, it is more apt to hold, of course, than otherwise. Moreover, it is shown that, whatever value the criterion may have, which is believed to be very little, its application to the sands studied by the writer would lead to the very startling conclusion that the Roubidoux and Jefferson City sandstones show more evidence of eolian action (though known to be marine) than the St. Peter itself, which has, in 12 out of 20 samples, the larger percentage on the finer side of the maximum. Such an interpretation, which results inevitably from the application of the supposed law, is itself sufficiently absurd to show that the principle is valueless.

Degree of rounding of St. Peter grains.

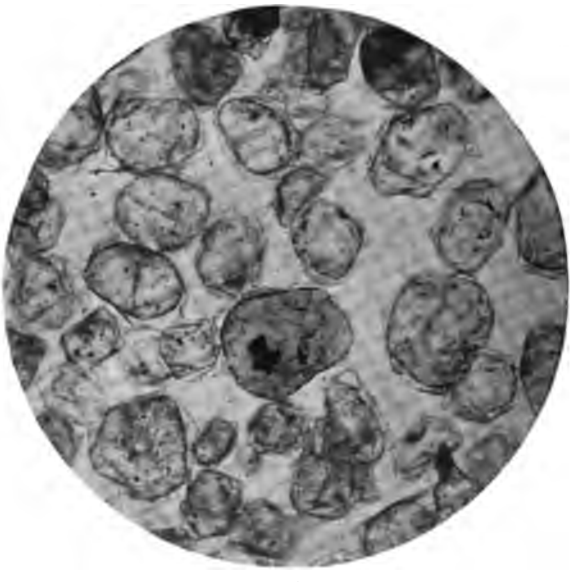
In interpreting sand grains, much importance has in the past been attached to degree of rounding. When attacking this phase of the St. Peter problem, there are two main lines along which investigation must proceed. The first concerns the validity of rounding as a criterion of the origin of sandstones in general, the second has to do with the application of the principles thus developed to the particular problem of the St. Peter. In much that has been written on the problem, there is lacking a clear conception of the fact that two distinct lines of investigation were involved.

Perhaps most fundamental, in such a study, is a proper idea of the causes of angularity of the grains of a quartz sand. There are three possible causes, which are vitally important. The first is the original irregularity of the grains, resulting from their crystallizing in the magma from which they were primarily derived; the second is the fracturing of these grains, in early or later stages of their history; and the third is recrystallization, or quartz enlargement, resulting from the addition of silica in solution in crystallagraphic continuity with the original grain developing secondary crystal faces and angles. It is not always possible in practice to discriminate between these various causes of angularity, but it is vitally important, for the sake of clearing up our ideas concerning the problem, to realize all the factors which may be involved. Rounding by solution, or by abrasion, either by wind or water, may destroy such angularity as once existed, whatever its cause.

It is a well-known fact that in many cases quartz enlargement can be detected, the old rounded nucleus being clearly visible within the crystal. As a rule, this is true only in those cases in which the old grain, having a coating of some impurity preserved within the enlarged crystal, shows the trace of its old surface. It is believed, however, since actual crystal faces are rare on quartz grains within a granite, that most sand grains which are angular because of crystal faces, have become so through quartz enlargement, even if no trace of the original surface can be seen. The cleaner the surfaces of the old rounded grains, the less commonly can such evidences of enlargement be detected. If they cannot be observed, it is of course impossible to determine how well-rounded the grains may have been, before enlargement took place. It must be borne in mind, then, that angular sands may once have been rounded, in their earlier history, and may again become round; and that this cycle may be repeated, not only once, but many times. Too much stress, then, must not be placed on the absence of apparent rounding in sand, unless the sand has been studied microscop-



A.



B.

Rounding and subsequent quartz enlargement in sand grains.

PLATE XIII.

A. St. Peter sand grains from Missouri.
S. 77. Tavern Rock Quarry, Klondike, Mo.

B. Roubidoux sand grains from Missouri.
R. 40. Sec. 9, T. 29 N., R. 4 W.

ically, and the fact determined that the present angularity is probably not the result of later enlargement.

Bearing this in mind, it may be well, in a study of the life history of sand grains, to consider what significance, if any, attaches to the actual degree of rounding. Here, again, emphasis must be placed on the principle already stated that the origin of sand involves three steps, derivation of the grains, transportation of the material, and its deposition. So far as the writer can discover, shape of grain may be related to forces involved in the first two, but not to the last, or at least, only very subordinately so. Emphasis must again be placed, also on the complex history which sand grains have undergone. To take grains of sand from a river bed, from a dune, or from a beach, or even from the ocean bottom, and to say "here we have features produced thus and so," is to ignore a vast range of factors which must be evaluated, if our conclusions are to have weight.

During a single cycle, from the production of the sand grains by the breaking down of a rock mass, be it igneous or sedimentary, to its reconstruction into a new sedimentary formation, that sand may successively be under the influence of wind, rivers and waves, not only once but many times. And even more than that, it may go through several such cycles from consolidated rock through sand to consolidated rock. In these cycles, it may be rounded, enlarged to new angularity, and re-rounded. Only in very exceptional cases, indeed, will it be possible to say with any certainty that the characteristics of grain noted in any given recent sand were impressed thereon by the agent under whose influence it now exists. Therein lies a vital weakness in most of the conclusions drawn from a study of recent sands.

It has usually been assumed by recent workers that wind was a more effective rounding agent than running water or waves. This conclusion was based largely on two assumptions, first that water held the grains apart, in such wise that they did not strike against each other efficiently, and second that the velocity of grains was usually greater in air than in water. That these are both factors in the problem, and that they act in the direction indicated seems a perfectly logical conclusion, though it is not easy either to prove or to disprove the assertions, or to evaluate the efficiency of the factors cited. Other factors, less commonly taken into consideration, however, at least partially counterbalance these tendencies. One is the fact that the sand grains in water are in more constant motion than are those moved by air. According to Grabau[32], Sockolow has observed that a wind of 4.5-6.7 meters per second (12 to 15 miles per hour) was required to move particles 0.25 m. in diameter, and one of 6.7-8.4 meters (15-19 miles per hour) to move grains 0.5 mm. in diameter. Since, however, it is a difficult matter to know just what velocity is moving given sand grains, these figures, while the best available, must be used with caution. It must be clear, however, both from casual observation, and from the above figures, that sand grains moved by the wind are likely to be resting a considerable percentage of the time. This conviction is strengthened by a study of average wind velocities, as given by Milham[33]. These are reported from numerous widely separated localities, through a period of years, in terms of monthly averages. The following table is a condensation from Milham;

Table of monthly averages of wind velocity.

Station.	Height of anemometer above ground in feet.	Length of record in years.	Average velocity, miles per hour.	
			Max. month.	Min. month.
Bismarck, N. D	35	34	12	8
Charleston, S. C	92	38	12	9
Chicago, Ill	274	15	19	14
Columbus, Ohio	222	?	10	6
El Paso, Texas	133	?	14	7
Indianapolis, Ind	164	12	12.1	7.4
Key West, Fla	53	38	11	7
New Orleans, La	121	39	9.4	6.1
Omaha, Neb	121	37	11	7
Philadelphia, Penn	184	?	12	8.4
Phoenix, Ariz	56	15	4.6	3.2
Portland, Ore	106	37	7	5
St. Louis, Mo	317	10	12.4	8.0
St. Paul, Minn	124	36	9.3	7.1
San Francisco, Cal	204	21	13.5	6.9
Seattle, Wash	151	?	7.4	4.8

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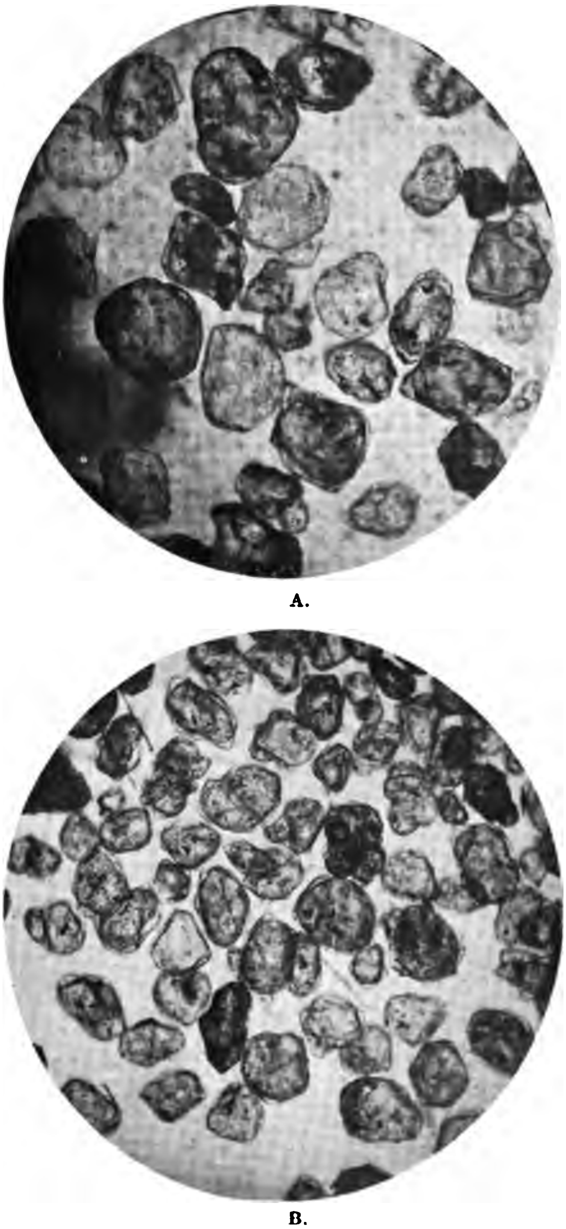
[32] Grabau, A. W., Principles of stratigraphy, 1913 p. 56.

[33] Milham, W. I., Meteorology, 1912, p. 153.

PLATE XIV.



Rounding and subsequent quartz enlargement in sand grains.

PLATE XIV.

A. Gunter sand grains from Missouri.
R. 49. Granite Bend, Mo.

B. Jefferson City sand grains from Missouri.
R. 9. Sec. 31, T. 33 N., R. 11 E.

It is obvious, from the record, that the wind velocity, for months at a time, averages less over large areas than that needed to keep average sized sand grains in motion. These records are taken high enough above the ground to avoid any considerable interference by trees and buildings. With the low, flat topography of St. Peter time, wind velocities possibly averaged somewhat greater. The figures must not be taken as an exact measure of conditions, but they indicate that, in a belt of prevailing westerly winds, such as probably (p. 217) obtained in the region in question in St. Peter time, it is more than likely that sand grains were not in as constant motion as they are in the ceaseless mill of a beach, or on a river bottom.

Another factor which tends to throw some doubt on the efficiency of wind in rounding grains is the observation of ordinary grinding methods. With low velocities, such as are obtained with a grindstone (5 to 10 miles per hour) wet grinding is much more efficient than dry, whereas dry grinding becomes more effective with high-velocity emery wheels. This conception seems to be borne out by experiments, not yet described, performed by Dr. Galloway[34], in which he found that only with high velocities, could he round sand grains in air currents, whereas much lower velocities accomplished the results in water.

Much stress has been placed on the supposed fact that grains of small size are not rounded in water, owing to the fact that they do not come into actual contact with each other, but are held apart by a film of water. The first reference to this principle is usually ascribed to Daubree[35], who says:

> "Chaque grain de sable s'arrondit graduellement sur d'autres grains de meme dimension, exactment comme les galets s'arrondissent entre eux. Mais il faut pour cela que ces grains soient tous assez gros pour ne pas entrer en suspension dans l'eau, at cependant assez fin pour suivre le mouvement du liquide.
>
> "La dimension des grains qui peuvent flotter dans l'eau très faiblement agitée parait etre d'evniron 1–10 de millimètres de diamètre moyen. Tout sable plus fin sera sans doute anguleux.
>
> * * * * * * * * *
>
> "D'Après les observations qui précèdent, les grains de sable balances par les vagues tendent à une dimsnsion *limitée*; cette dimension mimima, pour des matérlaux de meme densite, dépend de la vitesse de l'eau dans laquelle ils se sont uses. De là ces grès formés de grains arrondis d'une uniformité de grosseur si frappante."

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[34] Personal communication.

[35] Daubree, A., Etudes synthetiques de geologie experimentale, 1879 p. 256.

Ziegler[36] has attempted to carry the principle that small grains are not rounded by water still further, and to show "that grains less than 0.75 mm. in diameter could not be well rounded under water." This is practically equivalent to saying that quartz sands are never water-rounded, since, as has been shown (pp. 157-163) 0.75 mm. is near the maximum size of grain in typical quartz sands. Galloway[37] has conducted recent experiments to show that much smaller grains can actually be rounded by water, and that time is a much more important factor than is the character of the transporting medium in producing rounded grains.

There seems to be little reason to doubt that sand grains can be well rounded either by wind or by moving water. It does not seem to be possible to make any valid estimate of the relative rates of rounding by the two agents, but it has been pointed out that certain factors not generally considered tend to reduce the usually assumed superiority of wind action. A constant wind of high velocity would doubtless be very effective in rounding sand grains. Inconstant winds of average velocity are probably no more efficient than waves or even rivers. It does not seem necessary to invoke the aid of wind, therefore, to explain well-rounded quartz sands. These conclusions, while indefinite, are sufficient to indicate that rounding, however perfect, cannot be considered positive evidence of wind action. Since, however, the conclusion is not, and cannot be, backed by anything like a demonstration, and will probably not be accepted by many, it seems worth while to consider the application of the supposed criterion to the St. Peter sandstone.

The following photo-micrographs (plates XIII-XX) show beyond dispute that sands ranging in age from the Potsdam of Wisconsin through the Jordan of Iowa and the Gunter of Missouri, of Cambrian age, and the Roubidoux and the Jefferson City of Missouri of Beekmantown age, are made up essentially of grains that cannot be distinguished from those of the St. Peter on the basis either of size or of degree of rounding. All of these sands show some quartz enlargement, as does also the St. Peter. This feature is most

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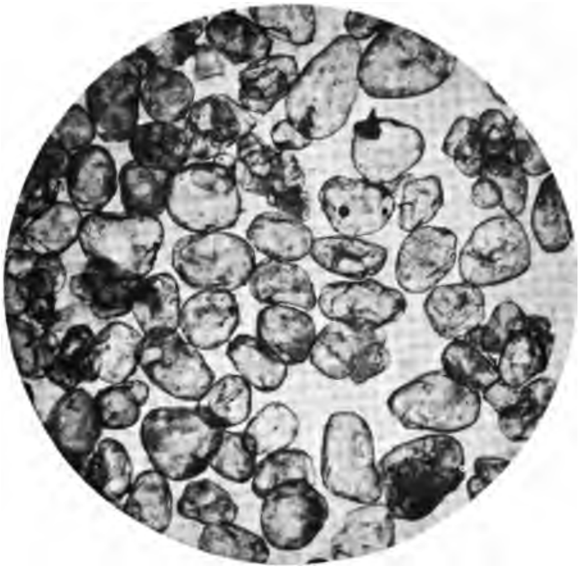
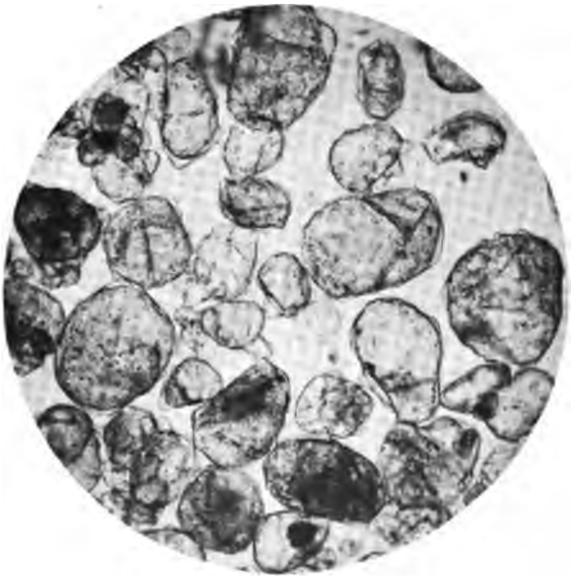
[36] Zeiglor, Victor, The rounding of sand grains; Jour. Geol. vol. 19, 1911, p. 654.

[37] Galloway, J. J., The rounding of sand grains by solution; Am. Jour. Science, vol. XLVII, 1919, pp. 270-280.



A.



B.

Rounding and subsequent quartz enlargement in sand grains.

PLATE XV.

A. **Potsdam sand grains from Wisconsin.**
S. 247. Kilbourne, Wis. Furnished by F. T. Thwaites.

B. **Roubidoux sand grains from Missouri.**
S. 207. Sec. 29, T. 31 N., R. 13 W.

marked, however, in those samples from the Roubidoux and the Jefferson City Group. The greater apparent angularity of these latter, as seen with a hand lens, is clearly owing to much more extensive secondary enlargement. Samples can be found, indeed, in these beds, in which the grains are still as rounded as are those of typical St. Peter. On the other hand, St. Peter samples can be picked, which show as much quartz enlargement as characteristic Roubidoux sands. Nevertheless the Roubidoux and the Jefferson City show greater average *apparent* angularity than the St. Peter; and this seems to be wholly a result of more complete enlargement, on grains equally well-rounded to begin with. Calvin[38] points out similar quartz enlargement in the New Richmond sandstone of Iowa, and gives an excellent photo-micrograph which shows the thoroughly rounded character of the original grains (plate XX, B).

It is not possible to say with absolute certainty when this enlargement took place, but the lack of any rounding of the new crystal angles would almost surely indicate that it occured after the formations were deposited where they now are. It seems to be somewhat significant that the enlargement is greatest in those formations which carry the most chert. Regardless of whether the silica was introduced into these beds from external sources, or only rearranged, from disseminated form, within the beds, quartz enlargement points to the active movement of silica-bearing solutions. And since chert consists of silica in a form more soluble than crystalline quartz, the more cherty formations would seem to afford the better opportunity for active growth of any quartz grains which might be present.

In order to account for rounding of the St. Peter grains, it has also been suggested that the St. Peter may have been deposited largely in the sea, after which the area emerged and became a desert of drifting sand which took on the rounded and frosted character of supposed desert origin. Under this supposition, two cases arise, either the region emerged sufficiently so that the sand was worked over thoroughly by winds quite to its base, or it stood at low enough level so that only its upper part was worked over. The second set of conditions would result in good rounding and wind polish in the grains in the upper beds, but not in the lower. This idea may be discarded at once, since a careful search shows that the grains in the base of the formation and even in the clearly marine Everton below, are quite as thoroughly rounded and frosted as those at the top. On the other hand, if the region emerged sufficiently so that the whole sand mass was drifted extensively enough to round and frost the basal grains as thoroughly as the top of the formation, it would allow of the mixing of underlying chert particles which would migrate up the dune slopes as discussed on p. 150. Of this action, no trace can be found. Moreover, if the drifting were sufficient to completely work over the basal beds, it would surely have produced wind-facetted pebbles out of the chert fragments so abundant in the old land sufrace upon which the sand rests (p. 150). No such wind-worn pebbles can be found. In any case such an origin would not account for the pratically equal degree of rounding and frosting in the older Jefferson City and Roubidoux beds, which has already been pointed out.

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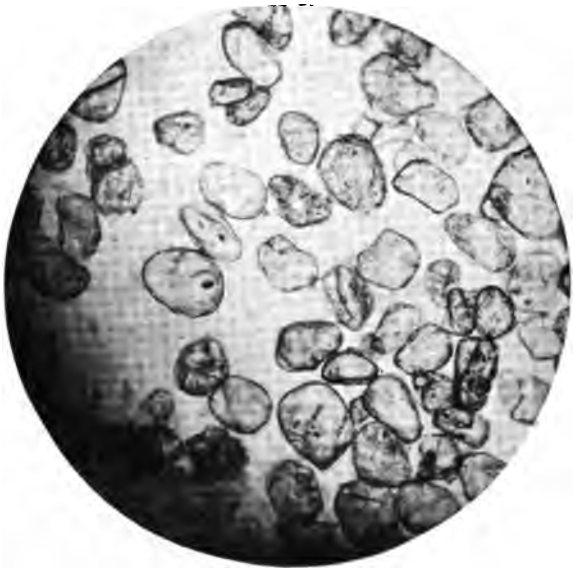
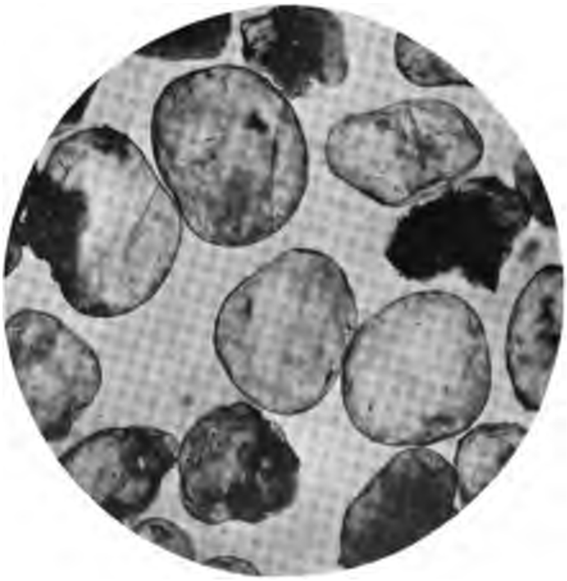
[38] Calvin, Samuel, American Geologist, vol. 13, pp. 225-227, 1894.

Summary.—Whatever the cause of the greater enlargement and present apparent angularity of the Roubidoux and Jefferson City sandstones, it is clear that in an earlier stage of their history, they closely approximated the St. Peter, in degree of rounding. Any explanation, then, that is advanced to account for the rounding of the St. Peter must account for the similar condition of the older marine beds.

No one familiar with the stratigraphy of the central Mississippi Valley would presume to postulate an extensive desert of drifting sand there during Roubidoux and Jefferson City time, as has been done for St. Peter time. The true explanation would seem to be that all of these sands were derived from a common source, probably to the north and northwest, as already suggested (pp. 207-210), under paleogeographic conditions sufficiently similar to produce comparable results. That these conditions involved areas of drifting sand on a vegetationless land would seem to be a necessary corollary of the absence of land plants in earlier Paleozoic time. Whether the wind was a more efficient factor in rounding than water is less to the point than that it was an *additional* factor. There would seem, however, no more necessity for invoking drifting dunes advancing into the St. Peter area than into the Roubidoux-Jefferson City area.



A.



B.

Rounding of sand grains.

PLATE XVI.

A. **St. Peter sand grains from Missouri.**
S. 11. Sec. 5, T. 43 N., R. 13 W.

B. **Jordan sand grains from Iowa.**
R. 232. Furnished by A. C. Trowbridge.

In so far as the St. Peter is derived from pre-existing sandstones, particularly from the Potsdam, is would also have the advantage of the very marked rounding already developed within that formation. That the difference between the two is not more striking is probably owing to the fact that rounding, once it has progressed as far as it had in the Potsdam, goes on very much more slowly than in earlier and more angular stages.

Frosting of the St. Peter grains.

The minutely pitted or frosted surfaces shown by certain sand grains, and frequently likened to ground glass, have commonly been considered to be a dependable criterion of wind-blown origin of sand grains. Again it must be said that such textural criteria, even though perfectly valid, are evidence only of conditions under which the sand has passed at some stage of its history, and may have no bearing whatever on conditions of deposition of the sand as a formation.

The familiar ground glass appearance of window panes, bottles, and other glass objects subject to natural sand blast gives conclusive evidence of the efficiency of wind in producing this characteristic. Sherzer[39] has placed great stress on this feature, in his study of the Sylvania sandstone. Galloway[40] was unable to produce these frosted surfaces, on grains rounded in water. He says:

> "The surfaces of quartz grains which I mechanically rounded in water were pearly, not glassy like freshly broken quartz, nor 'frosted' as in old, wind-worn sands."

The writer has noted the surfaces of glass fragments on the beach and in streams, that showed similar ground glass effects. While it is firmly believed that such surfaces can be effects by wave and river action, no convincing evidence has yet been secured that all of the wear in any given case necessarily resulted from attrition by water-borne grains. The possibility of the agency of wind-blown sand cannot be entirely eliminated. It is certainly not established that such frosting can be produced only by wind action, but the evidence seems to show that wind is probably much more efficient in producing such surfaces than any other agent we know. It follows, then, that these frosted grains are the best textural criterion we have of wind action on sand. This does not mean, however, that the sand must necessarily have been in drifting bodies, in the area where it is now found. The frosting of the grains may have been produced elsewhere at an earlier stage in the history, providing subsequent transportation has not been for long enough distances to destroy this surface.

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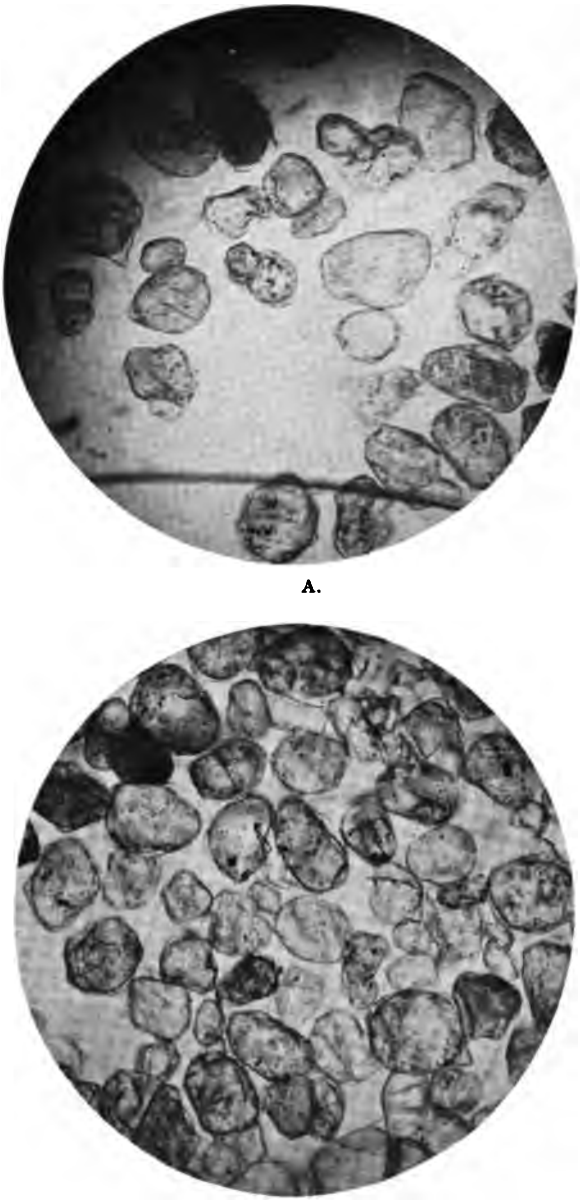
[39] Sherzer, W. H., Criteria for the recognition of the various types of sand grains; Bull. Geol., Soc. America, vol. 21, 1910, pp. 625-662.

[40] Galloway, J. J., The rounding of grains of sand by solution; Am. Jour. Sci., vol. XLVII, 1919, pp. 270-280.

The St. Peter sandstone shows to a notable degree this frosted character, and this has been considered one of the most convincing proofs of its wind-blown origin. A careful examination, however, has shown that the degree of frosting varies greatly, even in the St. Peter itself, some samples showing it almost not at all. On the other hand, samples of the Gunter, and the Jordan, and the Potsdam were studied that showed such surfaces as finely developed as in the most characteristic St. Peter. This feature, except when it is obscured by subsequent quartz enlargement, is seen better with a hand lens than with a microscope. Microscopic studies show that frosting is best developed in those samples in which quartz enlargement is least conspicuous, whereas the enlarged grains show the clear viterous surfaces. This discovery led to further investigation in the course of which it was found that in many of the enlarged grains the old frosting of the rounded core of the grain was still visible, through the layer of added quartz. The observed facts seem to bear out the conclusion that the older sands, including the Potsdam of Wisconsin, the Jordan of Iowa, and the Gunter, Roubidoux and Jefferson City of Missouri, all showed frosting in degree comparable to the St. Peter, and still show it where they have not undergone enlargement. In fact the St. Peter itself, where much enlarged, does not show this feature, except under the microscope, owing to the fact that with a hand lens only the outer surface, and not the frosted nucleus, is seen.

Any explanation, then, for the frosted character of the St. Peter grains must also account for similar conditions in the lower sandstones. If this characteristic is of eolian origin at all, it can be explained only by assuming derivation from a single vegetationless land mass to the north and west, on the surface of which the sands were wind drifted; a mass which

PLATE XVII.



Rounding and subsequent quartz enlargement in sand grains.

PLATE XVII.

A. **Roubidoux sand grains from Missouri.**
R. 195. Ava, Missouri.

B. **St. Peter sand grains from Missouri.**
S. 28. Sec. 19, T. 30 N., R. 13 E.

persisted from Potsdam to St. Peter time, as a continual source of sediment. A serious difficulty involved in this explanation is the question of whether frosting of the grains developed by wind in the area of the supply ground would persist through long transport by waves. It is believed, however, that after grains are once rounded, wear becomes very slow, and that such frosting might be preserved in those sands deposited moderately near the source. This may account for an apparently greater development of frosting of St. Peter grains in the states to the north.

Character of the basal conglomerate.

Careful search reveals almost everywhere at the base of the St. Peter group, a conglomerate consisting of pebbles of chert and limestone in an impure sandy matrix. Usually this conglomerate is only a few inches thick, but in a few localities several feet of it has been observed. These chert fragments are very little rounded, and at no point have pebbles been found that could be considered to be wind-facetted. There is not a sign of wind polish, or of facetted forms, and nothing comparable to desert varnish. If the area over which the St. Peter sands advanced was a typical desert of drifting sand averaging less than one hundred feet thick, this old floor must have been exposed many times to vigorous sand scour; and with an abundance of chert fragments, such as are demonstrated by the conglomerate to have been present, conditions would have been ideal for the production of facetted pebbles. Their absence appears to be highly significant. That this old land surface which was carved into considerable relief by the pre-St. Peter erosion, was exposed to wind action is undoubtedly true. Quite possibly much of the finer residual clay may have been removed by deflation, at this time; clay with chert fragments similar to that seen at the surface of the exposed Beekmantown beds in the Ozarks of to-day. But the lack of facetted pebbles indicates the absence of large quantities of drifting sand; and the lack of desert varnish on the pebbles or the bed-rock below suggests that the climate may not have even been particularly arid.

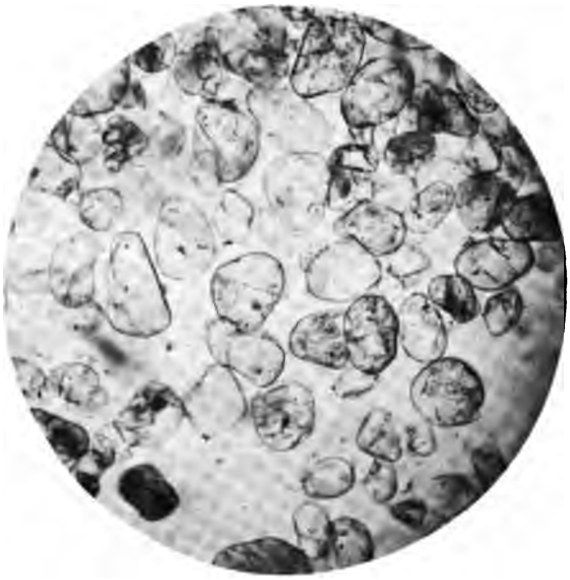
General summary of textural characters.—It has been shown that size of grain and uniformity of grain are not valid criteria for the eolian character of sand. Moveover, it has been pointed out that the St. Peter sand consists dominantly of the sizes usually ascribed to water action, and said to be coarser than are characteristic of wind work. Attention has been called to the fact that the St. Peter is entirely indistinguishable from earlier sandstones, particularly the Roubidoux and Jefferson City, both as to size and uniformity; and since the latter are clearly marine on the positive evidence of fossil content, the argument, on this particular basis, for the eolian origin of the St. Peter, fails completely.

Degree of rounding has also been shown to have less significance than has formerly been attached to it, as a proof of wind activity; and it has been pointed out that certain older marine sands also show rounding to an entirely comparable degree, so that even this factor cannot be assumed to prove eolian origin of the formation.

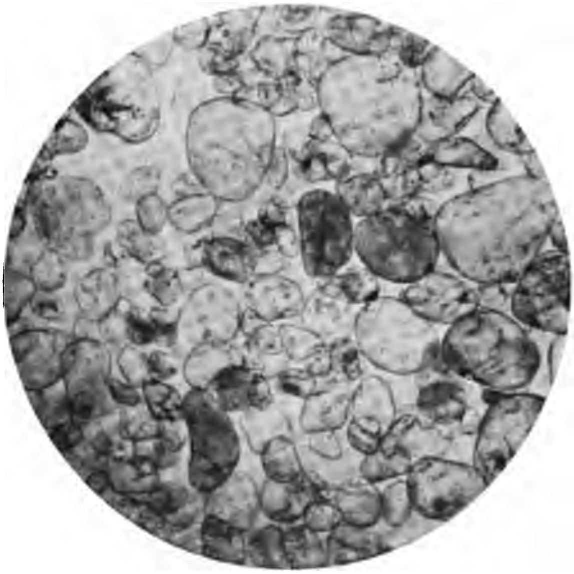
The most convincing argument that the St. Peter has undergone wind-drifting seems to be the frosted character of its grains. Emphasis, however, has been placed on the importance of understanding that all of these textural criteria, so far as they are valid at all, apply chiefly to derivation and transportation of the sands; and it is pointed out that since the St. Peter, in all these respects, is similar to the other sandstones of the region, some of which are clearly marine, we must look to a common history for these sandstones, and need only assume what appears obvious on the face of it, that they all were derived from a deposit existing under conditions favorable to wind activity; but that these textural criteria throw no light on the conditions of deposition of the formation.

STRUCTURAL FEATURES OF THE ST. PETER.

It is the intimate structural features of any sandstone that throw light on the conditions under which it was deposited, and it is to these, rather than to textural features, that most importance attaches in evaluating the paleogeographic conditions obtaining while the formation was being laid down. Among the structural feature of most importance are thickness, bedding, cross-bedding, ripple marks, and sun cracks,



A.



B.

Rounding of sand grains.

PLATE XVIII.

A. St. Peter sand grains from River Falls, Wis.

B. St. Peter sand grains from northeast Iowa.
Furnished by A. C. Trowbridge.

Thickness of the St. Peter.

Much has been said about the remarkable uniformity of thickness of the St. Peter formation, and statements have been made that this uniformity could have been produced only by eolian action. Here again we are confronted by a two-fold problem; the significance of thickness in general; and the thickness of the St. Peter in particular.

It appears to be pretty well established as a general principle that known marine formations are more uniform in thickness than known terrestrial ones. This is particularly true when the marine beds are contrasted with delta deposits, such as the well-known Paleozoic deltas of the eastern United States. On the other hand, we have so few well-authenticated eolian sand deposits that general observation fails us.

Since thickness depends upon inequalities in both upper and lower surfaces of a formation, two types of conditions must be analyzed. The lower surface of any formation will of course conform to the inequalities of the topography upon which it is laid down, and will be essentially independent of the agent of deposition. The only possible significance attaches, then, to the character of the upper surface. In the case of sand dunes, this will, within certain limits, be locally extremely irregular. Such a surface gradually lowered beneath an encroaching sea might, however, have these local inequalities effectively smoothed out. Concerning the larger features of irregularity such as gradual thickening or thinning of a formation in any given direction, we have less definite information. The writer, however, inclines to the view that in this feature marine beds will be more uniform than eolian. He knows of no evidence, however, which would convincingly bear out the conclusion.

Locally, the St. Peter varies greatly in thickness. According to Wisconsin reports[41], it ranges in that state from a single layer of sand grains to 212 feet, the variation at many places being abrupt. Trowbridge[42] cities changes from 123 feet to 223 feet in short distances in Iowa. The writer has already (pp. 15-16) presented similar data for Missouri. Since, however, this variation appears to result almost wholly from the unconformity at its base, the conditions are not at all significant. The average thickness appears to be somewhat greater in the upper Mississippi Valley than in the Ozarks, though the difference is not marked. This is such a situation as might result because of derivation from a northern land mass. The writer does not believe that any valid argument for eolian deposition of the St. Peter can be based on thickness. The local marked irregularities, which result from the unconformity at the base are not an argument for any particular conditions of origin, and it surely yet remains to be demonstrated that wind is more capable than the sea of distributing a uniform layer of sand over a large region. To the writer the great uniformity in thickness strongly favors accumulation in the sea.

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[41] Chamberlin, T. C., Geology of Wisconsin, vol. II, 1873-77, pp. 270-290.

[42] Trowbridge, A. C., The Prairie du Chien-St. Peter unconformity in Iowa; Iowa Acad. Sci., vol. XXIV, 1917, pp. 177-182.

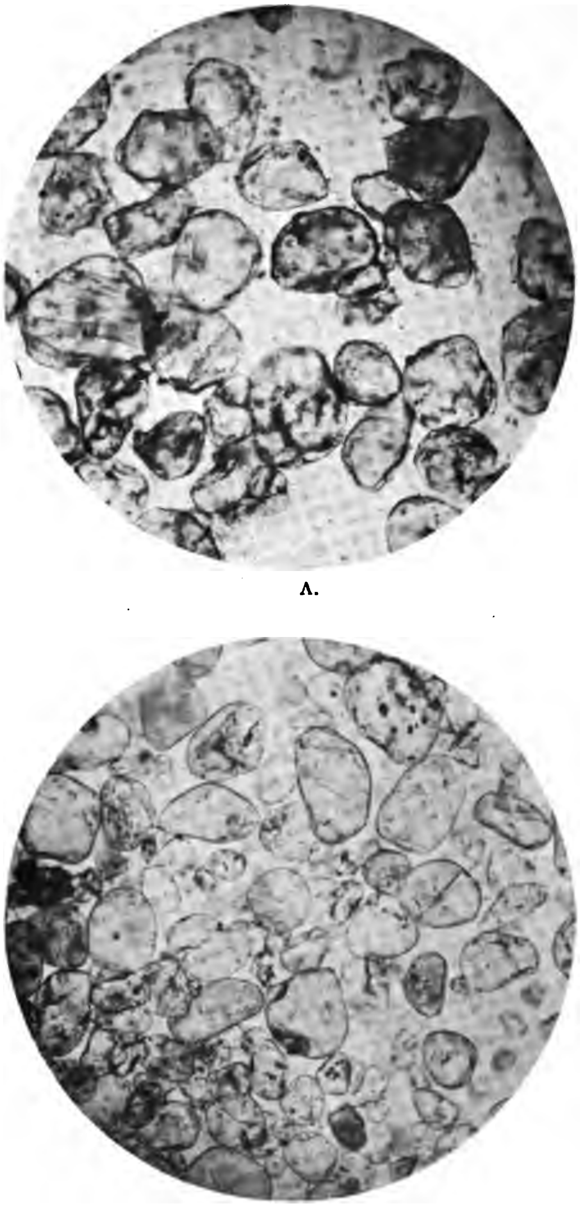
Nature of bedding in the St. Peter.

Many outcrops of the St. Peter appear massive, particularly on fresh exposure. On more weathered surfaces, especially when viewed at a distance, bedding stands out rather distinctly. For the formation as a whole, bedding is more conspicuous than cross-bedding though locally the reverse may be the case. In places mud seams and limestone lenses make the regularity of the bedded structure more obvious. Bedding is less conspicuous in the purer sandstones, chiefly it is believed, because there is too little fine sediment present to give the clay films that are so important a cause of bedding planes in many formations.

Compared with other sandstones, the St. Peter is intermediate in the perfection of its bedded structures. It is less bedded than the Roubidoux, but about the same as much of the Lamotte of Missouri or the Potsdam of Wisconsin. It is more regular than the Coconino of Utah and Arizona, in which the writer has found marine fossils, or than the LaPlata of the Colorado Plateau, which may possibly be an old dune deposit.

The prominence and regularity of bedding as contrasted with cross-bedding is brought out by photographs published by the writer in "The Sand and Gravel Resources of Missouri." Several of these, reproduced herewith (plates XXI-XXVI), show the character of the bedding particularly well. Photographs

PLATE XIX.



Rounding and subsequent quartz enlargement in sand grains.

PLATE XIX.

A. St. Peter sand grains from near LaSalle, Ill.
Furnished by J. Bridge.

B. St. Peter sand grains from Minnehaha Falls, Minn.
Furnished by C. P. Berkey.

published by Cady[43] and by Sauer[44] illustrate similar development of bedding in Illinois (plates XXVII-XXVIII). Like conditions are shown in Minnesota by photographs in the St. Paul-Minneapolis Folio (plates XXIX-XXX).

In the opinion of the writer, it is quite impossible for eolian action to produce over wide areas bedding as regular as that displayed by the St. Peter. It has been argued that the sand has been worked over by waves, thus giving to it a more regular structure than is possessed when first laid down. Such working would, of course, eliminate any pre-existing dune structure; but it is not conceivable that it could work into the middle of a 100 foot bed of sand, practically horizontal clay layers of considerable extent, and limestone lenses of importance.

Cross-bedding in the St. Peter.

While little has actually been published concerning either the character or the importance of cross-bedding in this formation, the dominance of the idea that it is a desert deposit has led to a very general belief that the St. Peter shows well-developed and widespread dune structure. The writer, from actual discussions with a great many geologists, knows that this impression is fairly prevalent. This impression is certainly not borne out by the facts. On the contrary, detailed work on a number of important sandstones, distributed over a wide area and stratigraphic range, including the Potsdam of Wisconsin, the Lamotte and Roubidoux of Missouri, the Cloverly and Mesaverde of Wyoming and the Coconino, the LaPlata and Mesaverde of the Colorado Plateau, shows that of all the important sandstones studied, the St. Peter is the least complexly or completely cross-bedded. Statements by Hall[45] and Norton[46] show that other observers have also noted the lack of cross-bedding in the formation. Worthen[47], describing the formation in Illinois, says

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[43] Cady, G. H., Geology and mineral resources of the Hennepin and LaSalle quadrangles; Ill. Geol. Survey, Bull. No. 37, 1919, pp. 33-36.

[44] Sauer, C. O., Geography of the upper Illinois Valley; Ill. Geol. Survey, Bull. No 27, 1916, p. 36.

[45] Hall, James, Report on the Geological Survey of the State of Iowa, vol. I, pt. 1, 1858, p. 337.

[46] Norton, W. H., Underground water resources of Iowa; U. S. Geol. Survey, Water Supply Paper No. 293, 1912, p. 71.

[47] Worthen, A. H., Economical geology of Illinois; Ogle County, vol. III, 1882, p. 119.

"Distinct stratification exists in most of the outcrops, and even lines of cross-stratification are not rare." A reader would certainly infer from this that bedding was more striking than cross-bedding. Wisconsin geologists report (p. 114) that cross-bedding is much less striking in the St. Peter than in the Potsdam.

Attention of course must be called to the fact that, to some extent at least, the lack of apparent cross-bedding is owing to the lack of impurities in the sandstone, which would aid in the production of any sort of stratification. In spite of this condition, however, bedding is better developed than cross-bedding, so that lack of impurities is certainly not the controlling cause. Furthermore, most of the cross-bedding that has been seen is on a small scale, is rarely very steep, and almost never intricate in pattern, as is that so remarkably shown in the LaPlata sandstone (Vermillion and White Cliff Sandstone of older reports); or like that described for the Sylvania[48], on which so much stress has been placed.

Those who accept as proved the eolian deposition of the St. Peter insist that the dune structure has simply been obliterated as the dune sands have been worked over by an encroaching sea. If Grabau and Scherzer are correct in their interpretation of the very complex cross-bedding of the Sylvania as dune structure, it is surely pertinent to inquire why an advancing sea in one case should have completely worked out all dune cross-bedding, whereas it is excellently preserved in the other. Owing to the fact that at many points the basal St. Peter beds rest in pronounced valleys in the older rocks, such portions at least, once they were filled up, would become especially well protected against re-working by waves. One would, therefore, expect to find the dune structures preserved in many places at the very base of the formation. Although sought most carefully in the field, no such occurrence has been noted in the areas studied by the writer. In fact the basal beds, as a rule, are the most regularly stratified, and this has already been explained on the ground that the slightly greater clay content near the base, believed to have been derived from the underlying soils, was a factor in producing a more prominent bedded structure.

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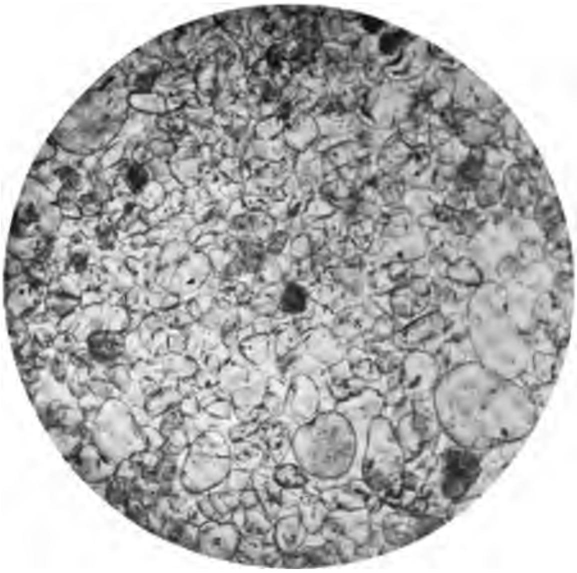
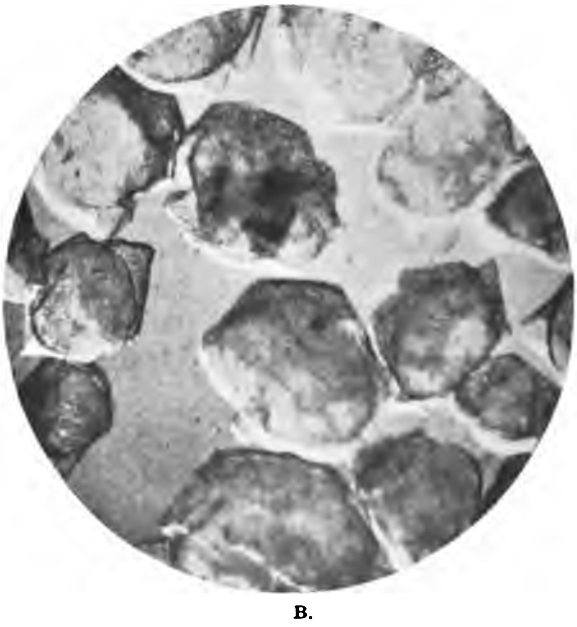
[48] Grabau, A. W., and Scherzer, W. H., Mich. Geol. Survey, Ser. 1, pub. 2, 1910, pp. 72-75 and 81.



A.



B.

Rounding and subsequent quartz enlargement in sand grains.

PLATE XX.

A. St. Peter sand grains from West St. Paul, Minn.
Furnished by C. P. Berkey.

B. New Richmond sand grains from Iowa.
After Calvin.

Ripple-marks in the St. Peter.

Ripple marks are rather rare in the St. Peter proper, though the writer has noted them at several points. The rarity of these features is perhaps connected with the remarkable purity of the formation, there being few clay films to preserve the ripples. That this is the real explanation seems to be suggested by their much greater prevalence in the less pure basal beds. The lower part of the Everton shows them in especial abundance. They are usually very small, rarely over an inch, and more frequently about a half an inch, from crest to crest, and are of the symmetrical or oscillation type. Such ripples must have been formed by wave action in water, and not by wind. Even in a desert area, symmetrical ripples might be produced in smal bodies of standing water, but in the case of the Everton these ripples are very abundant over wide areas, and are practically unaccompanied by those of the current type. It is almost certain, then, that the chief deposition of this part of the formation took place under water.

Ripples are described from Illinois which Worthen[49] thinks may be of eolian origin. Since he does not attempt to describel them, little weight can be attached to his statement. And moreover, while it is reasonably well established that oscillation or symmetrical ripples can be produced only under water, no satisfactory criteria appeared to have been developed by which one can discriminate between current ripples of aqueous origin and wind ripples.

The evidence of depth as deduced from ripple marks is so conflicting that it would seem to be of little value. Johnson[50] has summed up the existing evidence, and concludes that very closely spaced ripples of small dimensions may be produced either by small waves at shallow depth, or by large waves at much greater depths. Reasons will be given elsewhere (p. 216) for believing that the water was moderately deep.

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[49] Worthen, A. H., Economical geology of Illinois; Ogle County, vol. III, 1882, p. 18.

[50] Johnson, D. W., Shore processes and shoreline development, 1919, pp. 489-512.

Absence of sun-cracks in the St. Peter.

Attention has already been directed (p. 9) to the very extensive development of sun-cracks in the Roubidoux formation, at numerous horizons, and the proof that it afforded of frequent slight emergences. That this was not continuous terrestrial deposition, however, is attested by the fact that these sun-cracks often appear in thin layers between limestone beds, the cherty portions of which yield marine fossils. In general, these fossils are found only after careful search, but actually occur at all horizons from top to botton of the formation, and locally in great abundance, but always in the cherty beds.

The layers that show the sun cracks are usually thin, very sandy shales, which are cracked throughout their full thickness and which being softer, are soon eroded away after exposure, so that only the fillings are usually seen. In a few cases, however, the writer has seen the cracked layers themselves.

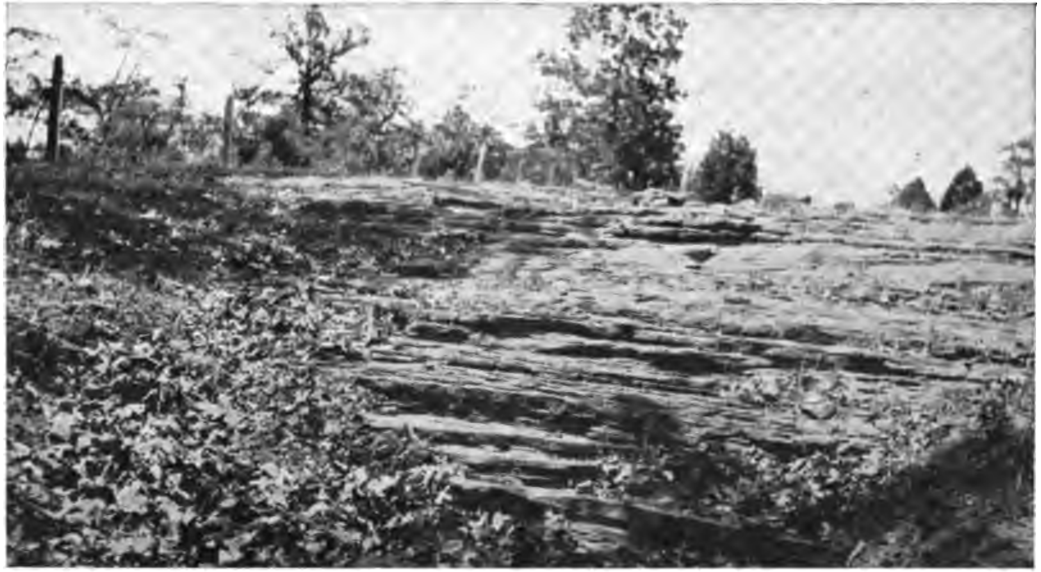
Similar sandy shale layers called "mud seams" are described (p. 24) from the St. Peter. A very careful search in these layers failed to reveal any sun cracks at all. If the formation were deposited on land, under desert conditions, the situation should be ideal for the formation and preservation of sun-cracks. Their complete absence, it would appear, can be interpreted only in one way. The St. Peter must have been laid down under water, and under conditions of sufficient depth and stability so that there were few if any of the frequent emergences that allowed the drying out and cracking of similar clay layers in the Roubidoux.

FOSSILS IN THE ST. PETER.

Much has been said about the extreme rarity of fossils in the St. Peter formation, and various explanations have been offered to account for it. Those who believe in the desert origin of the formation consider that the lack of fossils is exceptionally strong evidence that the beds were laid down on land. Those who believe the formation was laid down in the sea either think that conditions were unfavorable to life at the time, or assume that the formation once contained more abundant organic remains which have since been removed by solution.

In applying these arguments to the St. Peter, it must first be pointed out that the formation has yielded marine fossils at a

PLATE XXI.



Thin-bedded Everton sandstone along roadside; NE. ¼ Sec. 26, T. 37 N., R. 8 E., north of River aux Vases, Ste. Genevieve County, Mo. (*Mo. Bur. Geol. and Mines.*)

few points. There is a prevalent misconception that the few fossil heretofore found have come only from the top of the sandstone, and adherents of the desert idea have insisted that they were included through the working over by the sea of sands laid down on land.

The writer found fossils at the top of the formation (p. 26) in Southaest Missouri. A considerable fauna is reported from the limestones of the Everton formation in Arkansas at the base of the St. Peter group. Tubular cavities referred to Scolithus have been found at numerous localities, chiefly near the top of the sandstone, though the writer found them in Missouri not far from the middle, and in Illinois they are reported from the base[51]. The most extensive fauna, however, yet collected from the St. Peter has been described by Sardeson[52]. A few of his species came from the top of the St. Peter near Dodgeville, Wisconsin. Most of them, however, were collected near St. Paul. The fauna consists of 13 species of pelecypods, 7 of gastropods, 3 of cephalopods, 3 of brachiopods, a doubtful bryozoan, and a sponge. Fourteen genera are represented.

One of the most interesting features of this discovery, and one to which attention is rarely called, is the fact that several of the species are actually found in the body of the formation. At Dayton's Bluff, the collection came from a horizon 60 to 80 feet below the base of the overlying "Trenton". At Highland Park, two miles south, fossils were found in still lower beds, and near South St. Paul, a collection was made from strata intermediate in horizon between the two above cited. At three different horizons, then, well down in the St. Peter, marine fossils were collected. While it may be possible that working over by waves, of sand dune deposit might introduce bedded fossiliferous layers at this depth in the formation, the occurence throws considerable doubt on the interpretation of the bed as eolian.

The scarcity of fossils in other beds associated with the St. Peter invites certain interesting comparisons. Except in certain restricted areas, and at very few horizons, fossils are rare in the entire Beekmantown series of the Ozarks. Where found they are usually limited to the silicified layers. In fact, fossils are almost unknown in this series except in the chert beds. In the Roubidoux, for example, the writer has found fossils at the very top, at the extreme base, and at several intermediate horizons, sufficient to establish its marine character throughout. Every fossil found by the writer in the Roubidoux, however, has been secured from chert masses. Not a one has been seen in the limestones or in the sandstones of the formation. These sandstones, at places, grade laterally into the fossiliferous cherty beds, in such wise, however, as to show that they occupy the same horizon. Similarly the writer has been unable to find fossils in the thin sandstone members of the Jefferson City, Cotter, or Powell; and very few in the limestones. For the most part, the organic remains are now restricted to the cherts. In the Everton, fossils are reported from the limestone members in Arkansas. In limestones of similar position in Missouri, the writer has not found fossils, though search has been made. If this search were continued with sufficient care, fossils might quite likely be found at this horizon in Missouri. The writer's failure to secure any indicates their rarity even in the limestones.

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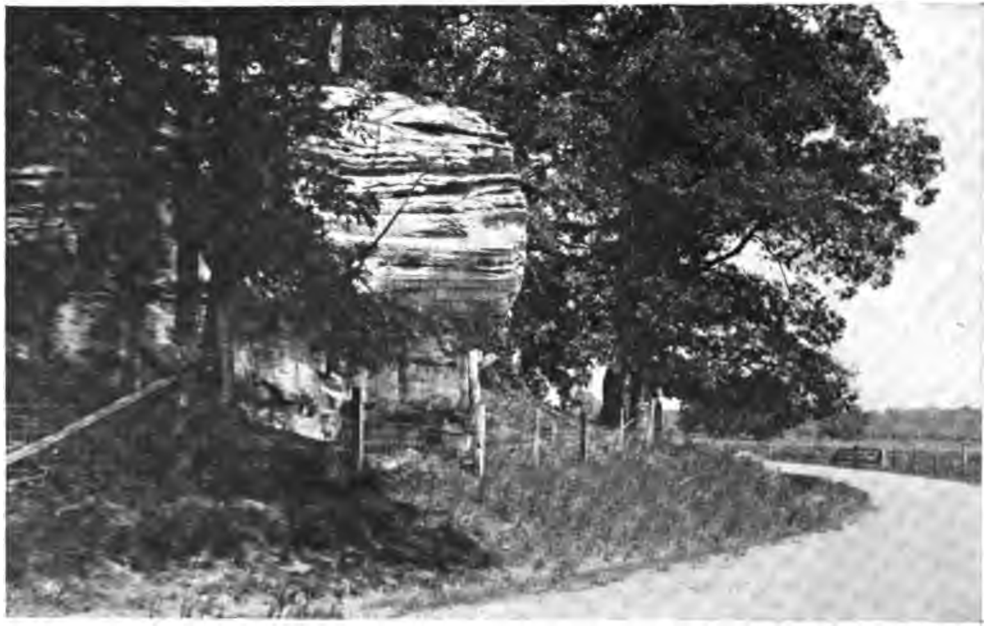
[51] Freeman, S. H., LaSalle County; Economical geology of Illinois, vol. II, 1882, p. 228.

[52] Sardeson, F. W., The St. Peter sandstone; Bull. Minn. Acad. Sci. vol. IV, 1910, pp. 64-88.

All the above formations occur below the St. Peter. In the Joachim limestone next above that sandstone all reports agree that fossils are also very rare, and although very careful search was made, the writer found only a single locality that yielded any. The overlying Plattin is much more highly fossiliferous, the change in the abundance of fossils being far greater between the Joachim and Plattin than between the St. Peter and Joachim.

The above conditions point to three factors, all of which seem to have been operative in bringing about the scarcity of fossils in the St. Peter. In the first place, the sudden change from Joachim to Plattin, both limestones, suggests a scarcity of faunas in the Jocahim sea followed by an influx in Plattin time. What the cause of this sudden change may have been is not apparent, since the physical conditions under which the two formations were deposted do not seem to have been greatly different. Second, there were during St. Peter and Roubidoux times rather extensive sandy bottoms, less favorable even than

PLATE XXII.



Cliff of St. Peter sandstone, just east of Dutchtown, Cape Girardeau County, Mo.
(*Mo. Bur. Geol. and Mines.*)

the Joachim or Everton lime bottoms, for the development of abundant life. And third, this scarcity of fossils in the limestones and sandstones, as compared with the chert, seems to be conclusive proof that fossils were once more abundant throughout these formations than they are now, and that silicification aided in their preservation, while they were destroyed in the unsilicified portions.

The conditions of preservation of the fossils found by Sardeson[53] is significant. He says:

> "The fossils are found as casts of shells that have themselves been entirely dissolved without leaving even a stain of color or a trace of calcium carbonate in the sand. The cavities left by the shells are closed up by a consolidation of the sand in some manner so that generally little more than smooth cleavage planes remain to define the fossils."

He further says:

> "The fossilization itself is not strange, but it reveals to us perhaps the reason that the St. Peter sandstone is so generally unfossiliferous, viz: because the fossils have been destroyed since the sandstone was deposited. One might dig up many fossils without seeing them, unless care be taken to prevent the casts from being crumbled."

Summary.—While fossils are scarce in the St. Peter, they are not unknown, and contrary to general belief, are not limited to the top of the formation, but occur at three horizons, well down in the sandstone, where they would not be likely to result from marine reworking of already deposited sand dunes. Whatever explanation is offered for the rarity of organic remains must account for similar conditions in the Roubidoux sandstone, a marine formation, and should explain a comparable rarity even in associated limestones.

It is believed that this is due in part to scarcity of life in the sea in which the beds were laid down, as suggested by the scarcity of fossils in the Joachim as contrasted with their abundance in the Plattin; and in part by lack of preservation, as indicated by the state of preservation of the few St. Peter fossils found, and by the greater abundance of fossils in the more silicified parts ot adjacent formations. The scarcity of fossils in the St. Peter is no better proof of terrestrial origin than is the entirely comparable scarcity in the sandstone members of the Roubidoux and Jefferson City, or even in the limestone of the Joachim.

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[53] Sardeson, F. W., op. cit. p. 69.

CHARACTER OF WATER IN THE ST. PETER.

The water yielded by the St. Peter sandstone is usually of good quality, especially where the sandstone is not deeply buried. In the central lower parts of the geosynclines, however, at numerous localities it is too strongly sulpho-saline to be potable. Its sulphurous character seems to be general over larger areas than its objectionable salinity. In the more deeply buried portions of the formation in northern and northwestern Missouri slightly saline sulphurous waters have been encountered, though for the most part they are fit for domestic use. So far as can be discovered the waters from this horizon in Iowa, Minnesota, and Wisconsin are of good quality. In Illinois the water is locally sulphurous, and is salty in the southern part of the state, where it is reached at great depths.[54] Sauer[55] speaks particularly of its sulphurous character, and describes pyrite as a constituent of the sand. In Indiana[56], Ohio[57] and Kentucky,[58] the water from the horizon usually correlated with the St. Peter is strongly sulpho-saline, locally approaching the salinity of sea water. Over large areas it is not a potable water.

So far as the origin of the St. Peter is concerned little importance probably attaches to the character of its water. The salinity is certainly not due to salt beds in the formation, since the hundreds of wells that penetrate the sandstone show no trace of either salt or gypsum. It is then presumably connate water enclosed in the sands at the time of their burial, completely freshened by circulation in the shallower parts of the formation near the outcrop, but still remaining salt in the more stagnant areas of deeper burial. Whether the sands were laid down on land and subsequently worked over by an encroaching sea, or were laid down directly as a marine formation would seem not to be indicated at all by the facts, since in either case they would become completely saturated by sea water.

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[54] Barlow, E., Udden, J. A., Parr, S. W., and Palmer, G. T., The mineral content of Illinois waters; Ill. Geol. Survey, Bull. No. 10, 1919, p. 14.

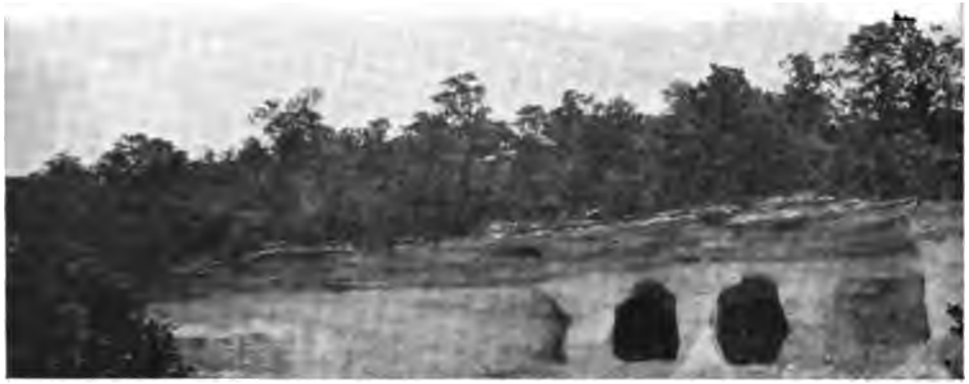
[55] Sauer, C. O., Geography of the upper Illinois valley; Ill. Geol. Survey, Bull. No. 29, 1916, p. 38.

[56] Phinney, A. J., The natural gas field of Indiana; Eleventh Ann. Rept., U. S. Geol. Survey, pt. 1, 1893, pp. 625-626.

[57] Fenneman, N. M., Geology of Cincinnati and vicinity; Ohio Geol. Survey, 4th ser., Bull. 19, 1916, p. 175.

[58] Shaw, E. W., Irvine oil field, Estill County, Kentucky; Bull. U. S. Geol. Survey, No. 661, 1918, p. 152.

PLATE XXIII.



Contact of St. Peter sandstone below Joachim dolomite, in an abandoned quarry near Pacific, in St. Louis County, Mo. Note how cross bedding gives a deceptive appearance of discordance.

(*Mo. Bur. Geol. and Mines.*)

The sulphurous character of the water is most probably derived from weathering iron sulphide, and may be either introduced from overlying or underlying formations, or may be indigeneous, or both. Some pyrites is known to occur in the St. Peter sand. This, if original, would be more likely to be formed in a marine, than in an eolian sand; but iron sulphide is so easily re-distributed by circulating waters that it is by no means easy to determine whether any of it was laid down with the formation.

It does not appear, then, that the character of the water in the St. Peter throws any light on the origin or the conditions of deposition of the sandstone.

CHAPTER III

PALEOGEOGRAPHIC INTERPRETATION.

BEEKMANTOWN.

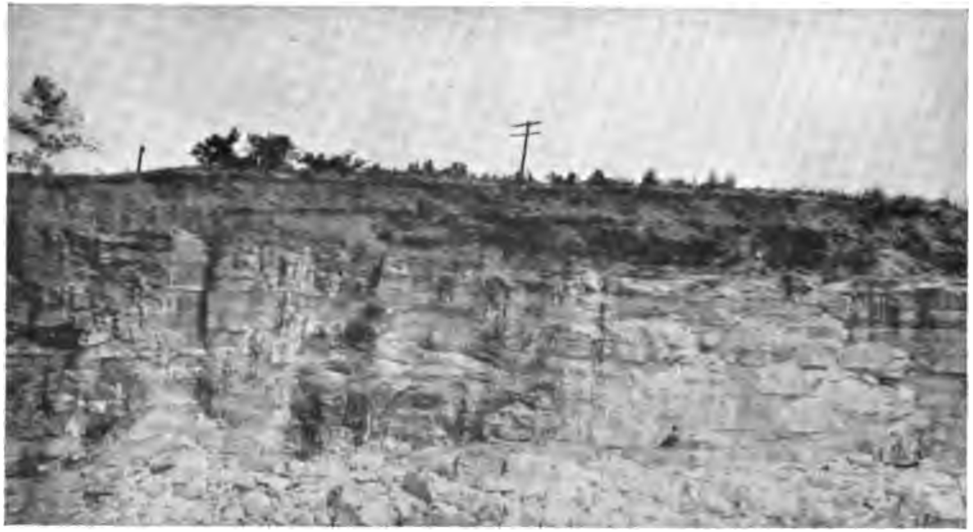
Sources of Beekmantown.

Throughout the Mississippi Valley region the base of the Beekmantown, as that unit is now restricted by Ulrich, is a dominantly sandy horizon, known in Missouri as the Roubidoux and farther north as the New Richmond. It is everywhere intimately interbedded with limestone layers, which locally make up 75 percent or more of the horizon. In Missouri it carries marine fossils at several horizons, and is clearly a typical marine sandstone (p. 10). It is known, through well borings and exposures, from the western boundary of Missouri eastward to central Illinois, and from the southern line of Missouri northward to central Wisconsin and Minnesota.

Since it everywhere throughout that extent rests on limestones belonging to what Ulrich terms the Ozarkian, the source of the sandstone material must lie wholly outside the region now occupied by it, and could by no possibility have been derived from the underlying rock formations, even though their surface underwent at least slight local erosion before the sands were laid down.

It then becomes pertinent to inquire from whence these sands could have been derived. To the far east, of course, was the more or less permanent land mass of Appalachia. Locally at least, this supplied the clastic material for the Deepkill shales. Elsewhere in the eastern region, however, the Beekmantown is sufficiently limey to indicate that the land mass was either low, or remote, and that it yielded little clastic material to the seas. It does not seem at all possible for these sands to have been derived from the land which yielded sediments for the Deepkill since only very fine clastics were being derived from that source, even in the eastern region.

PLATE XXIV.



Tavern Rock Sand Company's quarry in St. Peter sandstone, near Pacific, in St. Louis County, Mo. The overburden is loess. (*Mo. Bur. Geol. and Mines.*)

Southeast of the Ouachita geosyncline was also a land mass which gave rise to the Mazarn shale, physically and faunally similar to the Deepkill (p. 51). There is scant justification for assuming, however, that this land area, which was yielding fine shaly sediments to the trough on its north, could have furnished the sandstones. That the sands could have moved across this dominant trough in an essentially pure state, leaving the finer muds behind is contrary to all known principles of sedimentation.

The present distribution of the Beekmantown in the Rocky Mountains is too local and little known for us to be able to say how much of a land area existed there. In the vicinity of Colorado Springs, however, the Manitou limestone of that age reaches 250 feet in thickness (p. 130), and from the descriptions does not appear to contain a single bed of sand or shale throughout, a condition which would indicate that any land mass which may have existed in the vicinity was not contributing an important quantity of sediment to the seas. Farther north in the Rocky Mountains the Bighorn limestone of Trenton age rests directly on the Deadwood of Cambrian age (p. 135), so that direct evidence of the character of the land mass is not available. Since, however, this condition persists from the Black Hills westward at least through the Bighorns into the Absaroka Mountains, it is clear that for a long distance in that direction the crystalline floor was not then uncovered, unless in very local patches; and a floor of Deadwood shales and limestones, in which sandstone is actually a very subordinate element, would not present a very probable source of this sand. Moreover, the distances involved in its transportation from that locality would seem to be excessive, and it would have been obliged to move across what appears to have been a broad shallow geosyncline.

The Ozark center of old crystalline rocks has been suggested as a source. In the past, the view has been very generally held that this crystalline core persisted late into the Paleozoic, if not beyond. In any event, its area was so small as to be insignificant when compared with the total amount of sand in the Roubidoux and New Richmond. Careful estimates show that at the most, considerably less than 1000 square miles could possibly be assumed to have been exposed, as late as Roubidoux time. Moreover, recent studies carried on in the field by the writer show that, although the Roubidoux and younger formations, as well as older beds down to Gasconade, Eminence, and even Potosi, occur in places within a few rods, or even feet of the granite knobs, the writer has never yet seen any material clearly derived from the old igneous masses incorporated in any beds later than Gasconade, and very little in beds later than Bonneterre. The writer feels fairly confident that the later Cambrian or Ozarkian seas swept completely over and buried the old basement, and that its present exposures are not the result of pre-Cambrian relief, but of later Paleozoic or post-Paleozoic faulting. If any peaks did persist as islands as late as Roubidoux time, they were of very limited extent, and were not yielding appreciable quantities of clastic material.

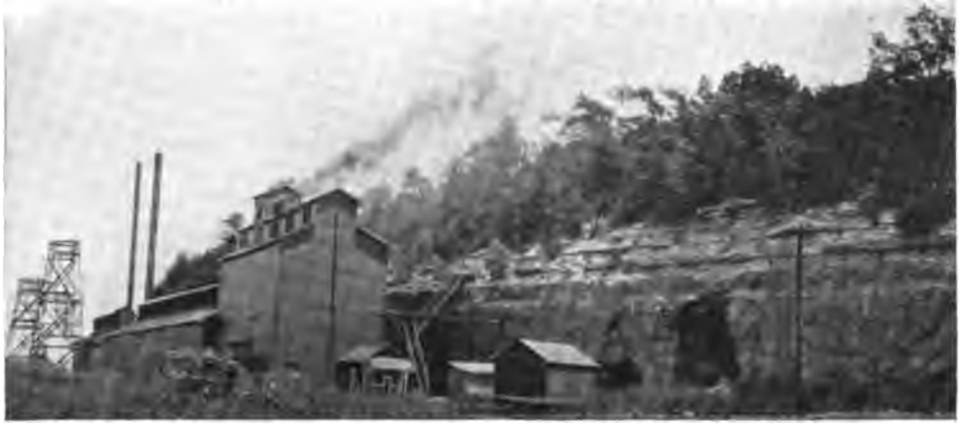
The only remaining source for the sands of the Roubidoux-New Richmond would seem to be the land mass to the north, consisting of the pre-Cambrian shield with a possible border of exposed Cambrian sediments. Since the New Richmond and Roubidoux, from the complex nature of their interbedded limestone and sandstone members, and from their contained marine faunas, appear clearly to be marine throughout, the shoreline would appear to have been for a considerable part of the time, at least as far north as central Wisconsin and Minnesota. How much farther north it may have fluctuated, it is impossible to say, since the northern fringe of the New Richmond, where it may have passed into a continental facies, has been removed by erosion.

Conditions of deposition of the Beekmantown.

The sand from this land mass was doubtless delivered to the sea by the ordinary agents of transportation, rivers and winds; but it was surely spread out over its present distribution largely by waves and currents. This conclusion will hardly be doubted by anyone who is thoroughly familiar with the general paleogeography of the Beekmantown and in addition knows the stratigraphy of the New Richmond and Roubidoux formations.

It is practically impossible to make any attempt at charting the currents, for these are dependent not only on the earth's rotation and the wind circulation, but also on the shape

PLATE XXV.



Quarry of Pittsburgh Plate Glass Company, Crystal City, Jefferson County, Mo. Shows cliff of St. Peter sandstone capped with Joachim dolomite. (*Mo. Bur. Geol. and Mines.*)

of the old shore lines, and probably even more directly, in the shallow epicontinental seas, on the configuration of the ocean bottom. If, however, the submerged area formed, as it seems to have done, the continental shelf between a land mass at the north and the deeper Ouachita geosyncline at the south, the dominant continental gradient was undoubtedly southward. Allowing an average gradient of six inches to the mile and assuming the shoreline to have been in central Wisconsin, the sea at the south line of Missouri would have been about 300 feet deep. Since, however, the Roubidoux as far as Missouri, even the portions containing marine fossils, is sun-cracked at several horizons, it is probable that the seas were considerably shallower than that figure, allowing repeated emergences with but little change of level. Such emergences involve some one of the following possibilities; first, lower gradients on the continental slope; or second, if the uplift were uniform, the emergence of the northern area to considerable heights, in order that the sea bottom in Missouri should be brought to sea level; or third, emergence by warping.

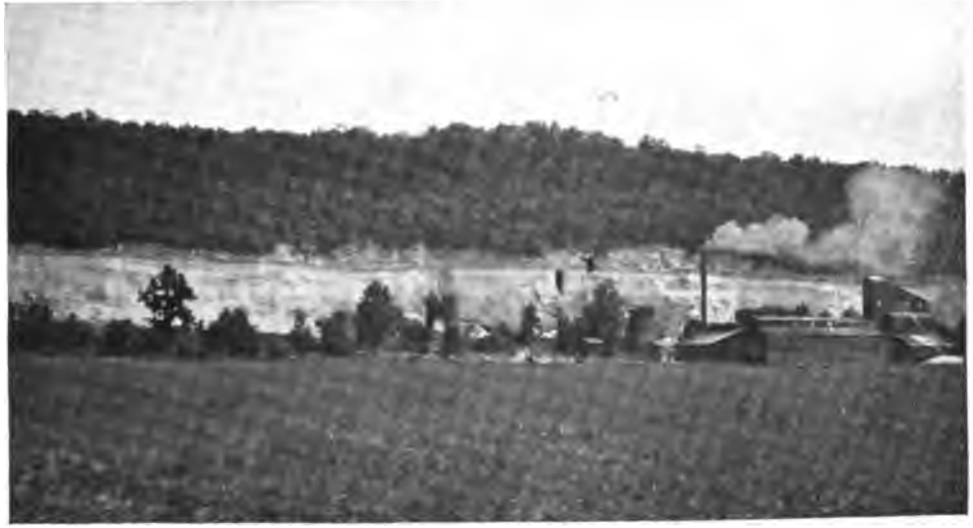
It does not seem probable that the land to the north, on the present site of the New Richmond, stood much above sea level during any part of New Richmond time, for there is no evidence of important channeling at the base of that formation, nor within it. It may be assumed, then, that the gradient was somewhat less, with shallower seas throughout.

It is also probable that the emergences that allowed exposure and sun-cracking of thin shale seams in the Roubidoux was in part the result of irregular warpings of the sea bottom, probably quite without system, that raised certain local areas and lowered others simultaneously. Such warping on a very gentle scale would help to account for the patchy distribution of sand and limestone in the formation. Whenever a local trough was formed, the sand moving across that area would tend to collect in the depression, where it would be protected against further movement. If the supply were not constant all the surrounding sand might be swept away, leaving that in the basin as an entirely isolated lens. Such a conception seems to demand that the surface of the limestone have a firmer consistency than we are in the habit of ascribing to lime oozes. The idea, however, is borne out by the fact that the submarine surface of lime beds seems not infrequently to be sufficiently hardened to break up into slabby masses, either by sliding or by storm waves, forming peculiar breccias.

The marine conditions of the Roubidoux are dwelt on at length here, because they seem to present somewhat different features from those of the St. Peter. The features of the land mass will be discussed in a later section (p. 216), for the reason that it is believed the Roubidoux and St. Peter were derived from a common source, under similiar conditions; and as more interest has attached in the past, to the problem of the St. Peter, the nature of this land area will be more fully considered in discussing that formation.

Next above the New Richmond-Roubidoux sandy complex lies a series of dolomites, essentially a unit, known in Missouri as the Jefferson City and Cotter, and farther north as the Shakopee, this group of formations also belonging to the Beekmantown. The marine character of this horizon is attested not only by the fact that it is a widespread dolomitic limestone, but by marine fossils throughout. This character of the formation signifies a marked diminution in the amount of the sand being contributed to the seas, as compared with Roubidoux time. Since these dolomites are sun-cracked in some of the slightly shaly horizons, we cannot infer, however, the deepening of the sea to any marked degree, and therefore should not assume any notable retreat of the shore line to the northward. The phenomena may be better explained by a gradual lessening of the available supply of sand on the land surface combined possibly with greater stability of the whole area. The presence in the Jefferson City, Cotter, and Shakopee of sandy layers at various horizons would indicate, however, that some sand was being contributed at intervals. That it came only at intervals might be ascribed to many different causes, no one of which can be pointed out definitely as the correct one. Slight local warping of certain areas with consesequent rejuvenation of the streams, is among the possibilities. Stream capture might locally alter the amount of sand being delivered by streams, tho stream capture is hardly to be expected on a land mass worn as low as this one probably was (p. 217). It is possible that the advance of a group of sand dunes either directly into some arm of the sea, or across the course of one of

PLATE XXVI.



Quarry of Pacific Glass Sand Company near Pacific, in St. Louis County, Mo. St. Peter sandstone capped with Joachim dolomite. (*Mo. Bur. Geol. and Mines.*)

the main drainage lines might locally have increased the quantity of sand being contributed.

At one time during the Cotter, enough sand was being carried into the sea to produce a sandstone member varying from 10 to 20 feet in thickness, known over wide areas of southeastern and southern Missouri. The localization of this sand layer, which does not appear farther north, is not improbably the result of local warping which produced the shallow protected trough, in which this sand layer accumulated as the material gradually worked southward down the submerged continental platform.

Where the shore line was at this stage is uncertain, though it is more than probable that the sea had already begun the general retreat which culminated in the break at the base of the St. Peter and closed the Beekmantown. In the central Mississippi Valley this retreatal stage, however, was apparently marked by fluctuations, since on the eroded surface of the Cotter rests another and still higher Beekmantown limestone, the Powell, the top of which Ulrich correlates with Division E of the New York Section.

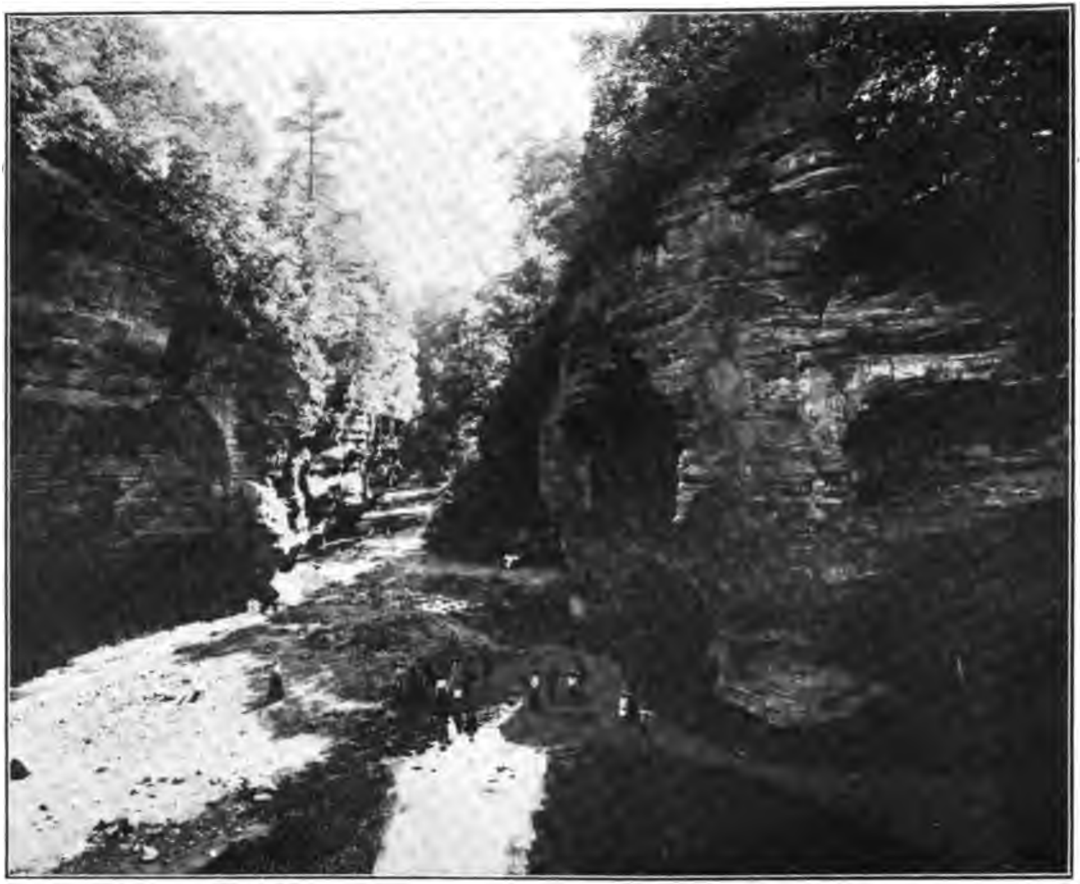
It is very difficult to know whether the retreat of the sea between Cotter time and Powell time was widespread or local since the Powell is not yet definitetly identified north of east-central Missouri. We know from the large number of local unconformities in the Ozark section, and from the abundance of sun-cracks in the rocks of that region, that it was always one of the positive elements, emerging more frequently than the surrounding areas, this tendency being even more marked in the later than in the earlier Paleozoic. The apparent absence, however, of the Powell, in the Upper Mississippi Valley, suggests a more general emergence at this time. The land stood above sea level long enough so that a residual soil was developed on the surface of the Cotter, with an abundance of chert pebbles. Then once more the Beekmantown sea, which farther east and south had probably continuously occupied the Appalachian and Ouachita geosynclines, spilled over the edge of the continental platform an unknown distance, and deposited the Powell dolomite, which is rather free from sand. How much of the northward fringe of the Powell has been removed by subsequent erosion, is not known, though it is quite doubtful whether the Powell sea ever advanced over the Upper Mississippi Valley.

THE PRE-ST. PETER EROSION.

Following the Powell advance came an even more extensive retreat, resulting in the so-called St. Peter break. It is generally known that this constitutes one of the most widespread breaks in the early Paleozoic column, being comparable with the Eden-Maysville gap and that of the Salinan. To many it has seemed that this was the normal place to draw the Cambrian-Ordovician boundary. This view has much to commend it, and, in fact for this country, is by all means the best solution of the problem. It would, however, introduce an enormous amount of confusion for this country to adopt such a division, radically different from that of other parts of the world. If later work shows, as general indications in North America seem to forecast, that the St. Peter emergence was the result of a true eustatic change rather than of local warping, and is therefore world wide, the justification for placing a system boundary at this point would be complete. Until further information is available, however, such a change would seem to be premature.

During this emergence, there was carved on the surface of the exposed beds a notable relief, variously reported (pp. 20, 113) at from 40 to 200 feet, the land appearing to be somewhat more rugged to the north. This erosion locally removed the Shakopee and New Richmond, exposing the Oneota, and in Wisconsin over large areas seems to have completely removed everything higher than Oneota, in one place (p. 113) actually exposing the Jordan sandstone. On this erosion surface was developed a residual soil which has been seen in outcrop in Missouri (p. 15) and Wisconsin (p. 112), and has been described from well borings in Iowa (p. 68), Minnesota (p. 98), and Illinois (p. 85). From the magnitude of the relief on this land surface, it would appear that the length of time involved in the erosion was considerable, probably actually greater than the balance of the time involved between Beekmantown and Lowville. In other words, more time was probably taken by erosion of the St. Peter break than by the laying down of the St. Peter group.

PLATE XXVII.



Deer Park Canyon, Ill., looking downstream. The cliffs are St. Peter sandstone.
(*Ill. Geol. Survey.*)

It should be obvious that the sands of the St. Peter, which now rest above this eroded surface, were not dragged out by beach action, in the form of a thick blanket following the retreat of the Beekmantown sea, because such a blanket immediately spread out would surely not allow of the carving of the irregular erosion surface on which this sand now rests. After the withdrawal of the sea, much time elapsed before this sand blanket became of appreciable quantity, else the sand would have protected the surface.

The marked relief, and the great removal by this erosion of formations to the north, would indicate that the more northern areas were longer out of the sea, which accords with the withdrawal of the sea towards the south, and its readvance from that direction. Not enough detailed observations are available to make it possible to trace out the pattern of hills and valleys on the Beekmantown surface, but there is no reason whatever to believe that it is, or was, anything other than the normal pattern of stream drainage, possibly modified somewhat by sinkholes, now known sparingly over the surface of the Jefferson City in Missouri. And the residual soils discovered are essentially like the residual soils of the Jefferson City on its present day erosion surface. There does not appear to be any reason, even, for assuming any radically different climate than now exists.

THE ST. PETER.

Source of the St. Peter.

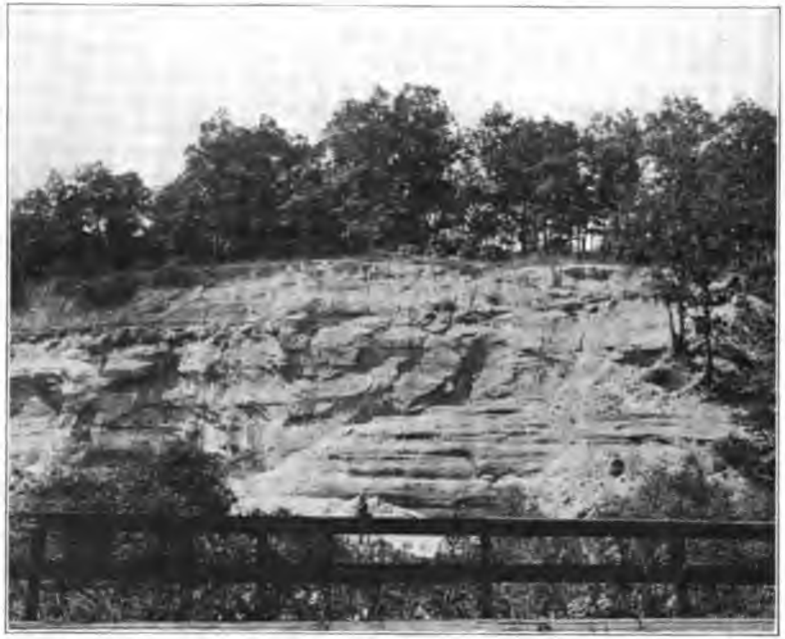
The sand which rests above this old erosion surface is a clean, pure quartz sand, and could by no possibility be considered in itself to be the basal conglomerate of the next higher formation, though it does carry at its own base a conglomerate of the type which might be expected to develop from the underlying cherty limestones; that is a chert conglomerate in an argillaceous sand matrix. The material for the main body of the St. Peter, however, must have been almost wholly introduced from outside sources, except the very limited amounts derived from thin sand lenses in the Jefferson City, and from the removal of the New Richmond, very locally, to the north.

Since it is certain that this sandstone was carried into the region from sources outside its present distribution, the next problem of immediate interest is to determine its source. While there was a land mass to the east, Appalachia, to which reference has already been made (p. 200), the fact that the Chazy equivalent of the St. Peter in the east is limestone, as well as the condition which seems to be revealed by drill records in Ohio, Kentucky, and Indiana (p. 125) where the St. Peter is said to be more truly an arenaceous limestone than a sandstone, would indicate that the St. Peter actually passes by gradual transition eastward into limestone, and was not derived from that direction.

Arguments have already been presented (p. 11) to indicate that the Roubidoux could not have been derived from the Ouachita land mass to the southeast, or from the Ozark center itself, and these apply with equal force to the St. Peter, so that no further consideration of that source seems necessary.

During the course of this work, the suggestion has been repeatedly made to the writer that the sand of the St. Peter quite probably came from the Rocky Mountains, far to the west. Arguments which seem to the writer to be reasonably convincing have already been presented (pp. 200-202) to show that the Roubidoux and New Richmond were probably not derived from that source. In an earlier chapter it has been pointed out (pp. 136-186) that the St. Peter and Roubidoux are so similar in size of grain, purity, and degree of rounding that it is reasonable to assume that they came from the same source and underwent essentially similar histories, and the source for the older sandstone has been referred with considerable certainty to the north.

It may be well to consider further, however, the possibility of a source to the west. In this connection the Nemaha Granite Range of Kansas suggests itself, both as possible source and as possible barrier. So little is known of this range as to render our conclusions open to question, but the most logical interpretation (pp. 127-130) it is possible to make with the present data would seem to indicate that the earlier Paleozoic seas swept unhindered over that area, as over the Ozarks, and that the range was not raised until at least as late as post-Trenton time, but earlier than the Pennsylvanian. If such an interpretation is correct, this range did not exist in St. Peter time, either as a source, or as a barrier to movement of sediments from the Rocky Mountains.



Quarry in St. Peter sandstone near Twin Bluffs, Ill.
(Ill. Geol. Survey.)

A further examination of the Rockies as a source reveals the following facts: Although during Beekmantown time this area does not seem to have been contributing much sediment, it was soon after elevated and eroded deeply enough to expose the crystalline core, after which, but not until Black River time, it was resubmerged, and received the marine Harding sandstone (p.), which carries a notable molluscan fauna closely related to the Platteville-Galena of the Mississippi Valley. The area, then, was land during the St. Peter deposition of the central United States. An examination, therefore, is essential, of the character of the rocks exposed. These consisted of patches of the Manitou limestone, non-arenaceous; a *very thin* Cambrian sandstone, the Sawatch; and the pre-Cambrian mixed crystallines. These, over large areas, consist chiefly of granites and granite gneisses, with subordinate amounts of mixed sediments, a source which would have yielded more clay than sand.

There appears, then, to have been a land mass in the Rocky Mountains during St. Peter time, which was capable of yielding a mixed sediment of sand and clay. If the St. Peter came from this source, the sand, whether transported by winds, by waves, or by rivers must have moved eastward. At present the St. Peter grades on the east chiefly into limestones, with only thin local shales. Had the transportation been by wind the finer constituents of the sediment might surely be expected to have settled in the Chazy seas on the east. If the chief transport tation were by rivers across broad land areas, the finer clays should also have largely moved eastward, unless there were dominant north or south winds, blowing transverse to the rivers, a rather improbable assumption, inasmuch as wind circulation is controlled largely by the earth's rotation. If, however, the transportation were by waves and currents, it is conceivable that a north or south drift, sufficiently strong to move the clays, but not to drag the sands, might allow of a rather complete sorting.

Toward the south in the Llano region of Texas, Mississippian rests directly on Beekmantown, and no beds equivalent to St. Peter are known. In the Arbuckles the Simpson, which seems to correspond in part to the St. Peter, is slightly shaly but this shale content appears to increase to the south and east, as though derived from the land mass of southern Arkansas.

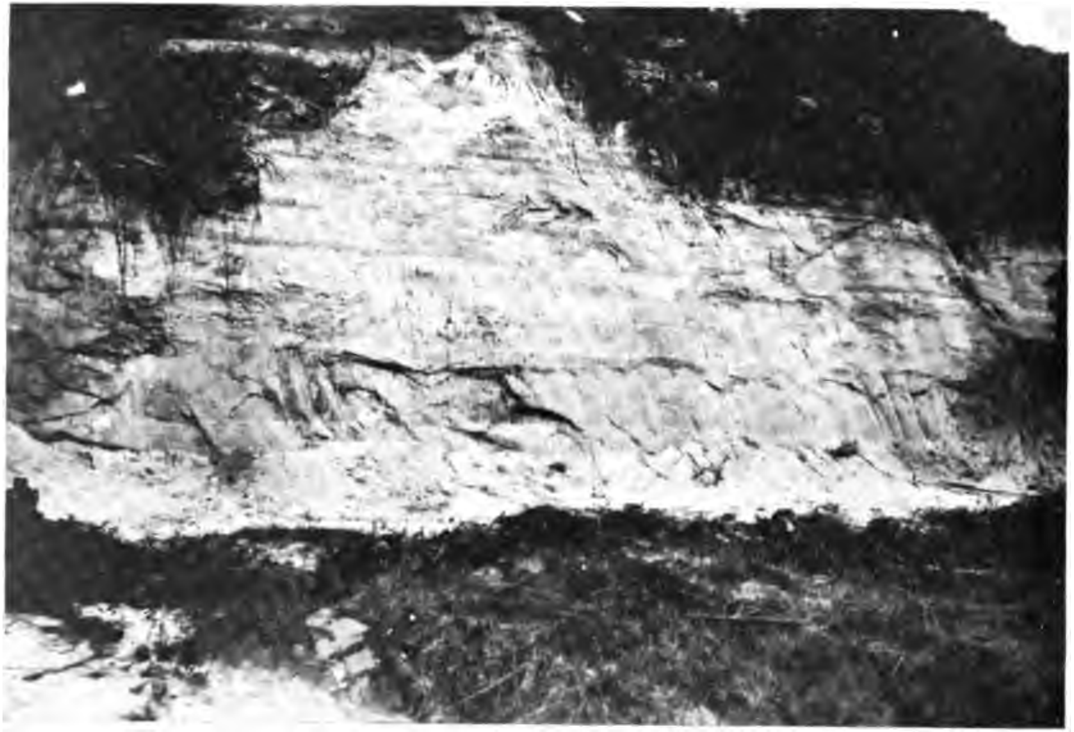
To the north no formations of St. Peter age are known. Nothing, then, is known of any shale beds which would represent the clay from the Rocky Mountain land mass to the west, and there is no evidence whatever that the St. Peter was derived from that source. The best evidence that it was not so derived is the fact that the sands of the Beekmantown of the Mississippi Valley could not have been derived from that region, and it hardly admits of doubt that the St. Peter came from the same direction as the Roubidoux-New Richmond of Beekmantown age. The writer doubts very much whether any sediment from the Rocky Mountain nucleus is incorporated in the St. Peter, and would expect to find the equivalent sediment from that source, both coarser and finer clastics, deeply buried beneath younger deposits, in the broad synclinal area of the Great Plains.

In the light of the conditions outlined in the foregoing paragraphs, it would seem much more probable that the sands of the St. Peter were derived from an area to the north and northwest, from which area were derived successively, and under rather similar conditions, the sediments of the Cambrian, Roubidoux-New Richmond and St. Peter.

Conditions of deposition of the St. Peter.

How these sands were transported from their source and under what conditions they were deposited constitute important questions comprising part of the St. Peter problem. The adherents of the eolian origin of the formation do not themselves seem to be wholly in accord in their views, although the more extreme of them certainly believe that the entire area at present occupied by the formation was a great interior desert over which the winds spread a mantle of loose drifting sand, in the form of migrating dunes. There are a number of facts, however, which tend to throw grave doubt on this interpretation. The remarkable rounding and frosting of the sand grains, which has always been advanced as one of the chief reasons for considering the St. Peter eolian, is developed to a practically equal degree in all the sandstones from the Potsdam up to the St. Peter; and since the marine Roubidoux-New Richmond member of this group, at least, is as typically rounded as the St. Peter, and locally

PLATE XXIX.



St. Peter sandstone in cliff opposite Minnehaha, Minn.

(*U. S. Geol. Survey.*)

shows the characteristic frosting where this feature has not been destroyed by quartz enlargement (p. 178), it would seem to be reasonably established that these features were largely developed by a similar history, and afford no proof of drifting sand, *within the area now occupied* by the St. Peter. That both of these sands probably underwent extensive drifting on the land surface from which they were derived has already been suggested and will be further commented upon in a later paragraph (p. 216-221).

Quite similarly the size and the degree of sorting of the sand grains of the St. Peter have been shown to be entirely comparable to that of the marine Roubidoux and older sandstones of the same area (pp. 136-186), and constitute no valid evidence that the *present site* of any one of these sandstones was necessarily a desert. As a matter of fact, it is far from certain that the above mentioned criteria actually *prove* wind-action at all, even though they may suggest it. But even if they constituted proof positive that the St. Peter had undergone wind-drift, other facts would still render it most probable that this took place largely in the area of derivation rather than in that of deposition.

Most striking of all the observed facts throwing light on the possibility of extensive sand deserts in the central Mississippi Valley during St. Peter time, is the character of the basal conglomerate of chert pebbles derived from the underlying cherty limestones. As already pointed out (p. 187) these nowhere show the character of wind-blown and facetted pebbles such as are described as typical of sand-swept areas. Concerning this point, the attention of the writer has been called to the fact that probably much less than one percent of this contact has ever been seen and examined. This is prefectly true, and if such a small proportion had been seen in a single area, the fact would lose much of its significance. But the writer has traced this contact for miles in Missouri, and has seen the conglomerates at literally dozens of rather widely separated localities, so that he feels no hesitation in saying that the conglomerates he has seen are absolutely typical of Missouri. Their character farther north has not been described in sufficient detail to justify definite conclusions.

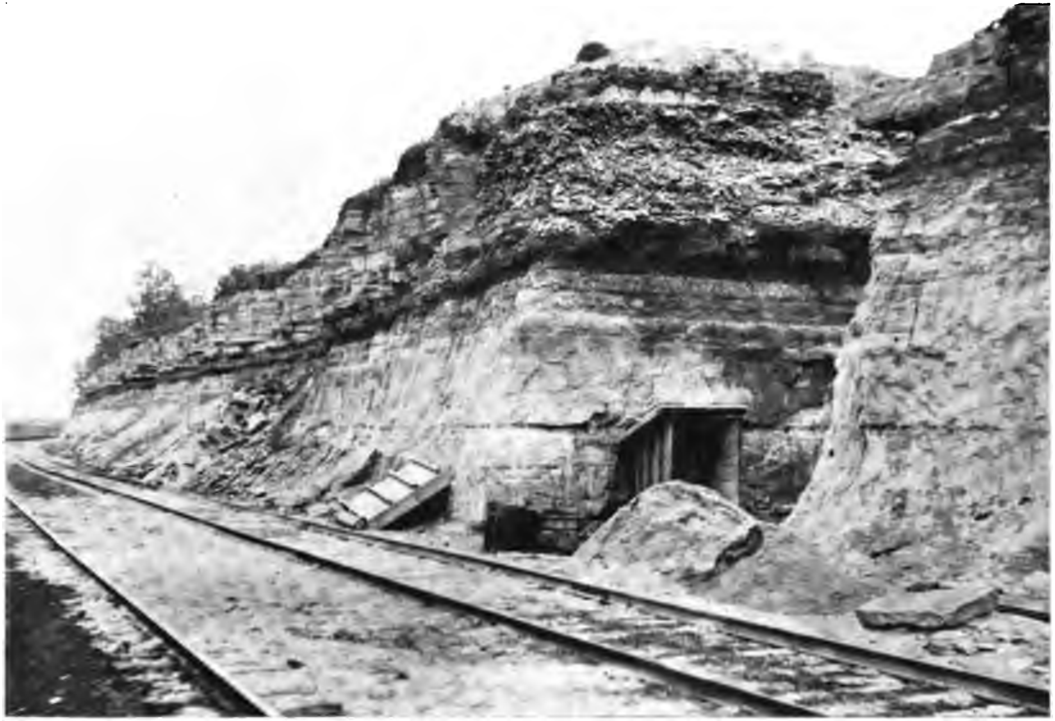
Another point of much interest is the nature of bedding and cross-bedding. It has been shown beyond any doubt (pp. 190-192) that bedding is much more perfectly developed than cross-bedding, nothing approaching dune-structure having been observed. It is said by those who favor the eolian origin of the deposit, that the advancing sea worked out all dune-structure. Why dune-structure should be assumed to be preserved in the Sylvania and worked out of the St. Peter has not been shown. Such a difference becomes all the more striking when it is remembered that in many places the basal St. Peter is protected in old valleys, which would render practically impossible any working over by waves that would not also cut away the pre-St. Peter hills. Nevertheless no sign of dune-structure is to be seen, even in these protected places. On the contrary, in several such places, the writer has seen well-bedded sandstones, which he has compared with dune sands resting in similar narrow valleys, in Arizona. The dune sands were intricately cross-bedded, and contrasted notably with the St. Peter.

The abundance of symmetrical ripples of the common type in the basal Everton sandstones (p. 193) next above the unconformity, the occurrence of regular and continuous shaly layers (p. 20), the intimate interbedding of limestone beds in the Everton with characteristic marine faunas through at least 100 feet of beds lying next above the unconformity (p. 42) and below the more massive sandstones of the St. Peter proper, all show clearly the ordinary marine character of the southern part of the formation, in the basal portion. The first deposits laid down above the unconformity, in that section, are undisputably marine.

Farther north the presence of important shale and even limestone beds, both in Iowa (p. 69) and Illinois (p. 86) and the occurrence, even at St. Paul, of marine fossils at three distinct horizons (p. 100) points to the persistence of these marine conditions far to the northward.

The conditions of deposition of the formation, then, are believed to be about as follows; After the post-Beekmantown emergence and erosion, the sea began to advance from the south, spreading over the southern edge of the contenental platform from the Ouachita geosyncline, from which it may never have completely retreated. Its first advance found a low limestone

PLATE XXX.



Upper part of St. Peter sandstone and basal beds of Platteville limestone, northeast Minneapolis, Minn.
(*U. S. Geol. Survey.*)

land mass with a mantle of ordinary residual clay soil. This it partly worked over, but owing to the degree of relief, which was obviously not planed down by wave attack, since it still exists, some of this residual clay was preserved in places.

Across this area from the north were flowing rivers which delivered some sands from northern sources, but the earlier submergence at the south was accompanied by the formation of considerable limestone, representing the lower Simpson of Oklahoma (p. 56) and, with the still further encroachment of the sea, the Everton of Arkansas (p. 41) and southern Missouri (p. 15); the sand being locally and irregularly distributed. During this stage it is quite probable that along the valleys of the main streams emerging from the supply ground to the north and crossing the Beekmantown surface, there may have been local dune areas, just as there are now along the valleys of those rivers that carry much sand. That these were an important feature of the landscape does not seem at all probable, in the light of data already presented. Such local dune areas, with the gradual shifting of the sands back and forth by variable winds, may account for the fact that here and there, locally, the sand-grains of the St. Peter seem to be more perfectly worn and frosted than is generally the case. Farther north such local dune areas might well have been more numerous.

After the seashore had progressed northward, at least past the central region of Missouri, and possibly far up into Iowa and Illinois, closing the period of Everton deposition, there appears to have come a warping which caused the emergence of the Ozark region, allowing the erosion of the surface of the uppermost of the Everton limestones. Reasons have already been given for believing that this emergence was more pronounced to the south, dying out northward (pp. 22-24) although the evidence for this is admittedly inconclusive.

It is entirely possible that this emergence may have brought out of the sea large areas of already deposited marine sands to the north of the limestone facies, allowing them to drift and become further rounded and sorted. It has already been shown, however, that the chief rounding was not produced in this way (p. 183), since the formation consists of well-rounded grains quite to its base. This emergence appears to have been followed by a tilting which submerged the area to the south and uplifted the source of supply somewhat, and it was following this episode that the great bulk of the St. Peter sandstone was laid down.

In a formation of the character of the St. Peter, it is difficult, if not quite impossible, to say with certainty where the shore was at any given time. That the sands actually encroached to some extent from their supply ground over onto the surface of the Beekmantown before the sea covered the entire area, is certainly to be expected; and this was probably accomplished both by streams and by dune-drifting. Such local dune areas may never have been completely worked over by the waves. Such a case may be that of the residual soil described by Twenhofel (p. 112) from the Sparta area in Wisconsin. He reports that a residual soil is there found entirely capping a hill beneath the St. Peter, in such wise that waves must surely have removed it, had it not already been protected by a blanket of sand. The preservation of such soil on the top of a hill is hard to account for in any way, but would probably be best protected in the way Twenhofel suggests. He also describes cross-bedding which he thinks is probably of eolian origin. The writer's own experience, which is limited to a very few observations, in Wisconsin, is that cross-bedding is more highly developed there than in Missouri. This would be true, even though the formation were entirely marine, because in the near-shore zone of more active wave-work, cross-bedding would be the more to be expected. Nevertheless it would not be surprising, even though the St. Peter were dominantly marine, as the writer firmly believes, to find some dune structure in this more northern area. It has already been pointed out (p. 213) that along the trunk streams, dune-drifting may have gone some distance. Elsewhere than along main drainage lines it was probably of only very local extent. Unless we assume a profound modification of the earth's axis of rotation, the area under discussion must have been then, as now, under the prevailing westerly winds. Within this area, at the present time, there is little evidence that sands would drift southward in large quantity. In fact, in discussing the origin of the Sylvania of Michigan, it has been postulated that it was derived from the St. Peter and older sandstones in Wisconsin, driven by the wind from west to east. If the prevailing direction of the wind in Monroan time was from the west, surely no logical reasons can be advanced to show why it was any different in St. Peter time.

The objection has been raised that a sea encroaching over this central area of marked relief would surely have planed away the hills of the old land surface, had they not been mantled by sand. To this it can be replied that in Arkansas, where there is a visible relief at the top of the Beekmantown, the first deposit laid down was a marine fossiliferous limestone. In Missouri, on a surface of large local relief (over 40 feet in 100 yards) the writer found that the first deposit over a considerable area was a complex of interbedded limestones and sandstones. In these cases the waves clearly were not prevented from planing away the hills by any protecting mantle of sand, and still the hills remain. The objection, therefore, has little weight.

It is believed that, as has already been postulated for Roubidoux time (p. 203), the prevailing continental slope was southward on the submerged surface of the Beekmantown beds; but with this difference, that the pre-St. Peter surface was carved into local hills and valleys. The irregularities in depth would surely exert a profound influence on currents, and since it is quite impossible to map the shoals and possible islands in the St. Peter sea, it is quite as impossible to describe its currents. There were undoubtedly of importance in distributing the St. Peter sand.

The objection has been advanced that the hills and valleys would prevent distribution of sand by the waves. On the other hand, the same feature has been cited as a barrier to dune-migration[59]. Neither intrepretation seems to be well founded, since in either case the sand would as it migrated, simply fill each valley until it began to spill over the ridge, into the next. In this way, there could gradually be established on the submarine slope a gradient which would ultimately become a graded slope for the given depth, size of waves, strength of currents, and supply of sand. Gradually, from time to time, by warping, shifting of shore lines, or modifications of the rate of supply of sand, this gradient would be rendered flatter or steeper.

It would not seem to be necessary, as so many have supposed in the past, that there must be an advancing or retreating shoreline to enable the sea to spread out an even blanket of sand. With a constant source of supply, and a stable land mass, there would seem to be no doubt that such a graded slope would be established, down which the sand must move so long as the basin was not filled up. As the basin became shallower and the gradient less, the rate of advance of the sand mantle would become exceedingly slow, as in the ultimate stages of peneplanation.

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[59] Trowbridge, A. C., Iowa Acad. Sci., vol. XXIV, 1917.

Quite probably the St. Peter was actually laid down in deeper water than the Roubidoux, since no suncracks have ever been noted in the shaly layers in Missouri, where the writer has studied the formation carefully in the field. Such cracks are very common in the Roubidoux, in similar layers, at numerous horizons. Their absence in the St. Peter, then, indicates not only that the material was laid down under water, but that it probably was not subject to as frequent emergence as the Roubidoux. Farther north, and in closer proximity to the shore line, it is more than likely that there were occasional emergences which brought local shoals within the range of wind action for considerable periods of time, and this may well account for the fact that some samples of the St. Peter show a much greater degree of rounding than others, even when the effects of secondary enlargement are eliminated from consideration.

Character of the land mass.

The next point particularly worthy of consideration is the character of the land mass from which the sand was derived. This, we have already shown, was in general to the north of the present site of the St. Peter sandstone, largely occupying the area commonly known as the pre-Cambrian, or Canadian shield, extending for an unknown distance to the north, the northeast and the northwest.

The region was probably not arid. The rainfall of the Upper Mississippi Valley at present is controlled very little by the matter of elevation, and over large areas practically not at all. The important control is the cyclonic storms of the prevailing westerly winds, drawing their chief moisture from the Gulf of Mexico. Since the area we are considering exhibited in St. Peter time a relation of land and water very similar to that now existing, there is certainly no reason to doubt an adequate precipitation. The fact that the rock materials are very completely weathered also suggests at least moderate precipitation. Even the Potsdam sandstone derived from this land mass carries very little undecomposed feldspar, except at its very base.

Through Potsdam time, and on throughout the early Paleozoic, the land mass probably never stood very high, and this is evidenced by the fact that weathering seems always to have kept well ahead of erosion, so that no coarse conglomeratic material was developed, except in the immediate vicinity of old monadnocks like the Baraboo Range. The lack of feldspathic constituents in the resulting sediments also indicates that weathering proceeded well in advance of the removal of the residual soil.

The land mass was apparently without vegetation, for, if we may judge by the best available evidence the world over, land plants had not yet developed by St. Peter time. If they had they were probably of minute size and easily destroyed. Practically no important remains of land plants are found before late Devonian time. This absence of vegetation quite probably was an important factor in increasing the efficiency of wind work, since it must have given even to a humid region many of the characteristics of a desert.

The wind circulation must, unless we assume profound shifting of the pole, have been much as at present. This factor, together with the other points already cited, the absence of vegetation, the comparatively flat topography and the deep weathering, seem to constitute vital points in the proper understanding of one of the apparent anomalies of the early Paleozoic sediments of the north central United States, namely the the remarkable rarity of shales as compared with sandstones, from the base of the Cambrian to the top of the St. Peter. The average igneous rocks should yield, according to Mead[60], several times as much shale as sandstone. The early Paleozoic section, derived from the pre-Cambrian shield, yields several times more sandstone than shale.

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[60] Mead, W. J., Redistribution of elements in the formation of sedimentary rocks; Jour. Geol., vol. 15, 1907. p. 250.

In such an area as postulated above, with its continental slope to the south, with deeply weathered soils, and with no protective cover of vegetation, westerly winds sweeping across the drainage lines would be given the maximum power of removing the clay in actual suspension, while drifting the sands into the rivers to be carried south into the sea. The dust, which was probably not carried far at any one time, except during unusual storms, came to rest to the eastward, each time on land instead of being dropped into the sea, until finally blown far eastward into the Atlantic ocean and lost beyond possibility of study. This process would account for the fact that the Potsdam, though it has many shaly beds, contains far less than the theoretically normal amount of clay. The wind drift would also aid in producing the perfection of rounding seen in these sand grains. With the close of Potsdam time and the northwardly encroaching Beekmantown sea, the northern fringes of the Potsdam were probably buried beneath overlapping limestones, and the land mass, now well worn down, contributed but little sand to the Beekmantown seas of the Mississippi Valley region, and that little even more completely sorted than before. The emergence in post-Beekmantown time first exposed a surface capable of yielding but little sand, but as the northern fringe of the Beekmantown beds was gradually removed, and supplied calcareous material to the Everton sea, a broad belt of Potsdam was likely to ultimately be uncovered. This actually occurred, since, as already pointed out (p. 113) pre-St. Peter erosion in one area in central Wisconsin even now shows St. Peter resting on Jordan.

With such a belt of Potsdam exposed along the border of the crystalline mass as now fringes the pre-Cambrian shield in central Wisconsin, but farther to the north of course, conditions would be particularly favorable for maximum wind action. While some sand would continue to be contributed from the crystallines to the north, much would now be derived from the newly-exposed Cambrian beds. This material, already once sorted over under very favorable conditions for rounding and removal of clay, would now undergo a second rounding and sorting of the same character, and when laid down in the St. Peter sea might be expected to show a remarkable degree of purity.

It is believed that the sea in which the St. Peter beds were laid down entirely submerged the Ozark region, and that the St. Peter once entirely covered that area. There are two chief lines of argument to substantiate this view. The first is that St. Peter maintains its high degree of purity everywhere about the present Ozark border. Had there been large areas of the Beekmantown beds exposed to erosion on an Ozark island, the bordering St. Peter would surely have carried much clay and considerable chert gravel, of the sort that the Ozark streams are now transporting in such abundance from the surface of the Beekmantown. The second evidence is the occurence widely distributed over the Ozark upland of patches of sandstone very similar in grain to the St. Peter. In fact, much of it was called St. Peter until the discovery of pockets of coal associated with it, and locally of Mississippian fossiliferous chert bowlders beneath it, since when it has been classed as Pennsylvanian. Now the Pennsylvanian sandstones in adjacent regions do not carry these well-rounded grains, and it is therefore believed that much St. Peter formerly present over the Ozark crest, was destroyed to produce the Pennsylvanian sandstones of this region.

As the shoreline gradually shifted northward, limestone deposition became dominant farther south, and the Joachim of Missouri and Arkansas represents, apparently, the same horizon as the upper part of the St. Peter in northern regions.

At the close of St. Peter-Joachim time, there was emergence in the Ozark region, as witnessed by the fact that the next formation rests on the eroded surface of the Joachim (p. 27). Slight evidences of such erosion are seen at the top of the St. Peter, farther north, but there is some reason to think that the emergence was greatest in the Ozark region, in conformity with its dominantly positive character. This emergence does not appear to have rejuvenated the northern land mass, now worn so low that it was furnishing practically no sediment at all.

With the re-advance of the sea, which seems to have come in very widely over the region, without a measurable time occupied by its spread, there suddenly appeared an abundant fauna of the general Lowville-Black River type, marking the base of the Plattin in Missouri and Arkansas and the Platteville in the upper Mississippi Valley. If the Everton, St. Peter, Joachim, and probably the Jasper of Arkansas, be considered the St. Peter group, then St. Peter deposition began earlier to the south, with considerable limestone, apparently before the main source, the Potsdam, had been uncovered at the north. With the influx of the added sand supply when erosion tapped this source, the sand encroached southward on the limestone areas, but as the land to the north was worn still lower, so that the supply was more limited, the limestone area again encroached northward on the sand, in the Joachim horizon. The base of the St. Peter group to the south (the Everton) is older, then, than any part of it in the north, while the Joachim to the south seems to be nearly coincident with the top of the sandstone to the north, since both seem to rest beneath essentially the same horizon.

It seems quite probable that the low, flat condition of the northern land mass at the close of St. Peter deposition allowed the Lowville-Black River sea to lap far up on the old crystalline shield. During the Decorah, there seems to have been some disturbance or slight uplift to the northwest, but not in an area that exposed any of the older sandstones to erosion, since the influx of clastic material is all fine calcareous shale which may have largely resulted from the erosion of something analogous to the Belt series, far to the northwest. In any event, the source was such as did not yield sand grains, and the Decorah thickens appreciably to the northwest, to the point where it was cut off by pre-Cretaceous erosion (p. 106). The top of the Decorah, where thickest in the vicinity of Minneapolis, seems to be the equivalent of the basal Galena farther south, (p. 106) the shale grading into limestone as the distance from the land source increased.

Following Decorah time there seems to have been an even wider submergence during which the sea probably covered much of the Canadian shield from Wisconsin north to Hudson Bay and from Lake Temiscaming west beyond Winnipeg. This submergence, also, it is believed, entirely overspread the Ozark region, or if not, left only a very low island of limestone, not deeply eroded. The absence of any sand layers such as would surely have resulted from erosion of the St. Peter makes it certain that formation was not then exposed.

The area of the Mississippi Valley then emerged, and remained land during most of Eden and Maysville time. During the Richmond, a wide submergence resulted in the laying down of a thin limestone, the Fernvale, over much if not all of the Ozark region and far to the southwest, while to the north, beginning simultaneously, or possibly a very little later, came the great influx of calcareous muds that produced the Maquoketa. This is more limey to the north, the Wykoff beds (p. 109), and more sandy to the south, the Thebes (p. 93), and suggests a change in the direction of the source of sediments that would require more detailed facts to work out than the writer has available. Since the Trenton (Galena-Kimmswick) wide submergence seems to have closed a portion of geologic time when the Canadian shield was an active source of important Paleozoic sediments, this study is not especially concerned with problems involved in later epochs. The wide distribution of Niagaran and Devonian limestones over the same area suggests that not for some time did it again become an important source of sediment.

GENERAL SUMMARY OF CONCLUSIONS.

The first chapter sums up the more important known facts of stratigraphy, not only of the St. Peter sandstone itself, but also of underlying and overlying formations, throughout the central Mississippi Valley region, so far as these seem to throw any light on the general conditions of derivation, transportation and deposition of the St. Peter sandstone. This is essentially a presentation of facts, without an attempt at interpretation.

Chapters two and three deal largely with intrepretation of the facts presented in the first section. In these chapters an attempt has been made to establish the following conclusions:

1. The composition and texture of a sandstone may furnish criteria regarding its derivation and transportation, but not regarding its method of deposition.

2. The history of the sand grains of a sandstone is usually so complex, including transportation successively by winds, streams and waves that textural criteria afford no proof whatever of the nature of transportation even to the *last deposit in which the sand is found.* The complexity of this history may be still further increased, if the sand passes through several cycles, from solid rock through sediment to solid rock again.

3. The structural and stratigraphic relationships in the field, including such features as the character of bedding, cross-bedding, unconformities, lateral gradation and similar associated phonomena, constitute the only valid criteria for determining the conditions under which a deposit was last laid down, and these may sometimes give a clue to the method of transportation *to that particular resting place.*

4. The purity of the St. Peter sandstone, while very remarkable, as compared with that of average sandstones, is, in respect to content of clay, iron, mica, heavy minerals, and carbonate, not sufficiently different from that of associated marine sandstones to demand any essentially different explanation of origin; the degree of difference actually existing being satisfactorily accounted for by assuming its derivation from one of the older, already well-sorted sandstones, the Potsdam.

5. Size of grain, in *pure quartz sands*, in general, is limited by the size of quartz grains in average igneous rocks, and is not a satisfactory criterion of wind-blown sands.

6. The size and uniformity of grain in the St. Peter is so near that of the Roubidoux marine sand that no discriminations as to origin can be made on such a basis.

7. The degree of rounding and frosting of grains, which has been used as one of the chief arguments for eolian origin of the St. Peter, may often be masked by secondary quartz enlargement, but making due allowance for such modification, the St. Peter cannot be distinguished, on this basis from the marine Roubidoux, or from older Cambrian sandstones, so that it is quite illogical to assume a different explanation for one than for the other.

8. The St. Peter shows bedding better developed than cross-bedding, and does not show typically developed dune-structure, even in the protected basal layers in the valleys of the old erosion surface.

9. There is no reason why, if the St. Peter is a dune deposit, an encroaching sea should be assumed to have completely worked out all such structure, and yet be assumed to have allowed it to be preserved, as reported in the Sylvania sandstone.

10. The St. Peter basal conglomerate of chert pebbles, widely developed on the pre-St. Peter erosion surface, shows

no effect of wind-polishing or development of facetted pebbles characteristic of work done by drifting and. Such wind modification would surely be observable if the St. Peter sand was drifted extensively across the area.

11. Limestone layers occur at many horizons, particularly at the south, but are known as far north as north central Iowa and northern Illinois, and indicate marine deposition.

12. Oscillation ripple-marks in sand layers, marine fossils in limestone beds, and extensive limestone deposits in general, occur in Arkansas and Missouri, next above the unconformity, showing submergence before the advance of the sand into the region.

13. Marine fossils are found in the St. Peter as far north as Minneapolis, not only in the uppermost transition layers, but also at three horizons, more than 60 feet below the top. These would not appear to have resulted from working over of dune deposits.

14. The St. Peter and Roubidoux appear to have been derived from a common land mass, which was almost certainly located to the northward, on the present site of the pre-Cambrian shield.

15. This land mass was not very high, sloped toward the sea at the south in which direction its rivers flowed, was probably moderately humid, but without vegetation because land plants had not yet developed, and lay in the belt of prevailing westerly winds.

16. Throughout early Paleozoic times, these conditions were particularly favorable for wind action, the westerly winds tending to float the finer dust and clay eastward across a continuous land mass until it was lost in the Atlantic, whereas the sand was drifted into the rivers and carried south to the sea, thus accounting for the lack of the theoretically proportionate amount of clay in the early Paleozoic sandstones.

17. The wind drifting undoubtedly was also an important factor in the rounding and frosting of sand grains in all the early Paleozoic sandstones from Potsdam to St. Peter.

18. Since these winds were presumably from west to east then as now, being controlled by the rotation of the earth, they would not seem competent to drift the St. Peter sand southward from its place of origin to its present distribution.

19. The land mass included not only the pre-Cambrian mixed crystallines, but also a broad fringe of Potsdam sandstone, which was exposed, possibly about the close of Everton time, by the erosion of the overlying Beekmantown limestones.

20. The derivation of the St. Peter largely from this Potsdam belt, in which the sands were already well assorted and rounded, together with the added sorting and rounding by wind work in the supply area, and by waves in the sea, explains in a wholly satisfactory manner the high degree of purity and rounding of its grains.

21. These sands were delivered to the sea both by rivers and to a minor degree directly by winds, and were distributed chiefly by waves and currents.

22. The shores of this sea were fluctuating, but during middle and late St. Peter time, were for the most part north of the Iowa-Minnesota line.

23. North of that line there is quite probably a small amount of St. Peter that is truly unmodified terrestrial deposit, for occasional slight local emergences not improbably allowed of wind-drifting and rounding, accounting for local areas of exceptionally rounded grains; but even here marine agencies were probably dominant in deposition.

24. South of the Iowa-Minnesota line, conditions of both transportation and deposition were almost wholly marine, and in this area there did not exist during any part of St. Peter time, a great interior desert of drifting sand.

VITA.

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Normal School, River Falls, Wis. (1906-1907).
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Columbia University, 1920-21.
University Fellow, University of Wisconsin, 1911-1912.
University Fellow, Columbia University, 1920-1921.
Phi Beta Kappa, University of Wisconsin, 1911.
Gamma Alpha, University of Wisconsin, 1912.

Sigma Xi, University of Wisconsin, 1912.

Assistant in Geology, Williams College, 1912-1913.

Assistant Professor of Geology, Missouri School of Mines, 1913-1918.

Associate Professor of Geology, Missouri School of Mines, 1918-21.

Professor of Geology, Missouri School of Mines, 1921.

Member American Association for the Advancement of Science; Society for the Promotion of Engineering Education; American Institute of Mining and Metallurgical Engineers; Geological Society of America.

Publications.

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